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# UTILITY OF MODELING AND SIMULATION IN THE DEPARTMENT OF DEFENSE: INITIAL DATA COLLECTION


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Henry K. Simpson, *Defense Manpower Data Center*
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# PREFACE

This paper was prepared by the Institute for Defense Analyses (IDA) under the task order, Defense Modeling and Simulation, and responds to an objective of the task, to "provide technical support to operational activities of DMSO, e.g., assessing the benefits achieved from use of modeling and simulation." The work was sponsored by the Defense Modeling and Simulation Office (DMSO), Office of the Director of Defense Research and Engineering.

IDA research staff members and military and civilian personnel from Department of Defense Components were members of the Modeling and Simulation Benefits Task Force set up by the DMSO Modeling and Simulation Working Group. The initial objective was to retrieve documented accounts of the benefits of modeling and simulation. The Task Force conducted its collection effort during the period of March to September of 1995.

The efforts and contributions of the individual members of the Modeling and Simulation Benefits Task Force, under the direction of LtCol David A. Bartlett, United States Marine Corps, are gratefully acknowledged. The following IDA research staff members reviewed this document: Dr. Richard J. Ivanetich and Dr. Jesse Orlansky. Their contributions are also acknowledged.

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# EXECUTIVE SUMMARY

The Modeling and Simulation Working Group, under the auspices of the Defense Modeling and Simulation Office (DMSO), authorized the formation of a Modeling and Simulation Benefits Task Force (MSBTF) to capture documented reports of the quantifiable benefits of modeling and simulation (M&S). This effort is an initial step in fulfilling Sub-objective 6-1 of the *Department of Defense Modeling and Simulation Master Plan*, to quantify the impacts of M&S, with the results incorporated into the longer-range Impact Assessment.

The MSBTF first met February 23, 1995, continued meeting monthly, and stood down on September 21, 1995. This report describes the Task Force's efforts and findings.

During the Task Force's "data capture" period, responses were received from two Requests for Information (RFI), Task Force members collected inputs from their respective Services and Agencies, and formal studies were collected from Federally Funded Research and Development Centers (FFRDCs) and Department of Defense (DoD) Components. The RFI conducted for the Task Force received 12 responses. A separate RFI conducted for the test and evaluation community received 15 responses. Overall, Task Force members collected over 90 contributions.

While no formal assessment could be accomplished based on the relatively small amount of information gained in a limited period of time, an informal meta-analysis—an analysis of other organizations' analyses—is included in this report. Meta-analysis has two serious shortcomings: it is based on information often a year or more old, and it is based on information typically biased towards the positive. The positive bias stems from the tendency to underreport negative results and the proponent's natural desire to share positive results. The Task Force provided some old and some very new inputs. FFRDC inputs, while recently published, were sometimes based on data collected in prior years.

## Findings

The applications of M&S to acquisition are many. Twenty case studies of Target Interaction, Lethality and Vulnerability showed a 30-to-1 return on investments in M&S support for milestone decisions and the Cost and Operational Effectiveness Analysis process. The Army Missile Systems Command reported a total of over $320 million in cost avoidance or savings from 10 case studies. Eight case studies were provided from the Virtual Proving Ground, U.S. Army Test and Evaluation Command. Two similar events were conducted for Apache Longbow Force Development Test and Experimentation, one using extensive simulation and the other using physical equipment. The simulation-supported event executed twice as many trials, with fewer personnel, in less time, at lower risk to personnel, for $700,000 versus the $4 million spent in using physical equipment.

Training applications of M&S were commonly used and the results were positive. Reporting was thorough on individual skills training, including both cognitive and psychomotor skills. Cognitive skills trainers, typically computer-aided instruction, paid for themselves in five years or less. Psychomotor skills trainers, e.g., flight simulators, driver trainers, conduct of fire trainers, and maintenance trainers, were all shown to be cost effective when properly mixed with training on the real equipment. At this level, analysts have well-established theories and experimental methods for conducting analysis. The same is not true for unit training, particularly of high echelon units. The high cost of a Joint or Combined exercise precludes the repeated, controlled experiments necessary to gather meaningful data on the benefits of additional learning trials. However, multi-million dollar savings are reported when comparing computer-assisted command post exercises to field training exercises.

Although M&S are used extensively in analysis, few reports documenting benefits were found by the Task Force. No reports were received claiming cost savings due to the application of M&S to analysis. Information provided by members of the analytic community suggests that they tend to measure the effect of their analysis on the decision-making process rather than the effect of M&S on their analysis. The effect of M&S on analysis, while real, is problematic to quantify. In contrast, the training and acquisition functional areas were more likely to gather quantitative data, specifically cost data.

Across functional areas, measures of effectiveness (MOEs) were not universally agreed upon. Consistency within functional areas was somewhat better. Analytic frameworks, including MOEs, need to be developed and applied consistently throughout DoD. Frameworks should be unique to each functional area and perhaps even functional sub-areas. As analytic frameworks are developed, they should be disseminated as recommended best practices.

Finally, a formal reporting mechanism does not exist for gathering information, nor do the methodologies exist for objectively assessing the value of using M&S. If the effects of M&S are to be collected, assessed, and disseminated, then methodologies should be determined and reporting pipelines should be established from the M&S developer and user communities through the DoD Components to DMSO.

# 1. INTRODUCTION

The Modeling and Simulation Working Group, created under the direction of the Defense Modeling and Simulation Office (DMSO), authorized the formation of a Modeling and Simulation Benefits Task Force (MSBTF) to capture documented reports of quantifiable benefits of modeling and simulation (M&S). This effort is an initial step in fulfilling Sub-objective 6-1 of the *Department of Defense Modeling and Simulation Master Plan* [DMSO 1995], to quantify the impacts of M&S, and will be incorporated into the longer-range Impact Assessment. This report describes the Task Force's efforts and findings.

The MSBTF first met February 23, 1995, continued meeting monthly, and stood down on September 21, 1995. The data collection effort occurred during the period of March 1995 to September 1995.

## 1.1 TASKING FROM DOD M&S MASTER PLAN

The *Department of Defense Modeling and Simulation Master Plan* [DMSO 1995] contains six broad objectives. Objective 6, "Share the benefits of M&S," the basis for the Task Force's formation, has three sub-objectives:

- 6-1: "Quantify the impacts of M&S."
- 6-2: "Educate potential M&S users (DoD, Congress, other government agencies, industry)."
- 6-3: "Support bi-directional technology transfer."

Sub-objective 6-1 further states that to quantify the impacts of M&S, the following actions must be accomplished:

- Collect and analyze data from ongoing efforts, planned experiments, and demonstrations to assess the impacts of M&S.
- Develop quantitative measures of the benefits of M&S (e.g., readiness impact, cost savings, and effectiveness) to (1) allow assessment of the utility of M&S and (2) support investment decisions.

- Establish the DoD-wide impact of M&S.

DMSO has initiated three activities in response to this tasking:

- The Institute for Defense Analyses (IDA) has collected information on 48 projects and 17 activities sponsored by DMSO in fiscal years 1992 through 1994 [Hammond et al. 1995].
- The MSBTF has conducted an initial data capture on benefits from Department of Defense (DoD) Components, the results of which are reported here.
- A sustained, long-range Impact Assessment has begun, employing the previous efforts as input.

## 1.2 TASK FORCE TIMELINE

**Table 1. M&S Benefits Task Force Timeline**

| | |
|---|---|
| Task Force meeting (kickoff) | February 23, 1995 |
| Interim results distributed | March 10, 1995 |
| Meeting, submit and discuss major points | March 23, 1995 |
| Meeting, agree on major report points | April 20, 1995 |
| Draft report distributed for Task Force review | May 15, 1995 |
| Meeting (final), discuss draft report | May 25, 1995 |
| Final report completed | September 21, 1995 |

## 1.3 TASK FORCE MEMBERSHIP

The membership of the MSBTF was drawn from the Services, Office of the Secretary of Defense (OSD), Federally Funded Research and Development Centers (FFRDCs), and private industry. LtCol David A. Bartlett, DMSO, chaired the Task Force. Composition of the Task Force is shown in Table 2.

**Table 2. M&S Benefits Task Force Members**

| Member | Organization Represented |
|---|---|
| Mr. Matt Aylward | MITRE Corporation |
| Ms. Michelle Bailey | Naval Air Warfare Center, Weapons Division |
| LtCol David A. Bartlett, USMC | Defense Modeling and Simulation Office |

| | |
|---|---|
| Mr. John Bishop | Institute for Simulation and Training, University of Central Florida |
| Colonel Guy M. Bourn, USA | Department of the Army, Office of the Deputy Chief of Staff for Operations |
| Mr. Tom Brown | Arnold Engineering Development Center |
| Mr. Albert R. Burge | Office of the Under Secretary of Defense, Acquisition and Technology |
| Mr. Bob Curtis | DATAMAT Systems Research |
| Mr. Michael L. Darby | North Star Institute |
| Major Dean E. Fish, USMC | Marine Corps Modeling and Simulation Management Office |
| Mr. Trevor Huth | Loral Federal Systems |
| Mr. Don Johnson | Office of the Under Secretary of Defense, Personnel and Readiness |
| Dr. Franklin L. Moses | Army Research Institute for the Behavioral and Social Sciences |
| Mr. Fred A. Meyers | Office of the Under Secretary of Defense, Acquisition and Technology |
| Dr. Jesse Orlansky | Institute for Defense Analyses |
| Mr. Ron Prishivalko | Defense Information Systems Agency |
| Dr. Henry K. Simpson | Defense Manpower Data Center |
| Mr. J. Stephen Schroeder | Arnold Engineering Development Center |
| Mr. Ernie Smart | Institute for Simulation and Training, University of Central Florida |
| Dr. Robert D. Smith | Naval Air Warfare Center, Weapons Division |
| Dr. D. Robert Worley | Institute for Defense Analyses |

## 1.4 REPORT OVERVIEW

Quantified impacts for M&S applications in acquisition, training, and analysis are summarized in Chapters 2, 3, and 4, respectively.

Appendices A and B survey the use of various quantitative and qualitative measures of effectiveness (MOEs). Appendix B, in particular, describes methods of analyses used in three case studies.

A list of references is provided along with an annotated bibliography, covering the full range of material collected by the Task Force. Abbreviations and acronyms are given at the end of the report.

# 2. ACQUISITION APPLICATIONS OF M&S

## 2.1 TARGET INTERACTION, LETHALITY, AND VULNERABILITY (TILV)

TILV refers to the mechanisms by which a warhead or similar device can defeat a target [TILV 1995]. The TILV area addresses the tools, methods, databases, and supporting techniques needed to assess the lethality and vulnerability of all weapon systems, including aspects of design, effectiveness, and survivability. Modeling and simulation provide a significant portion of the TILV capability and, in particular, an attractive alternative to destructive test. Table 3 [TILV 1995] depicts the Return on Investment (ROI) of M&S support for milestone decisions and the Cost and Operational Effectiveness Analysis process. *The typical ROI was between $20 and $30 returned for each $1 invested.*

**Table 3. TILV Return on Investment**

| Program | Type Analysis | Total Invest ($M) | Direct Savings ($M) | ROI | Program Result |
|---|---|---|---|---|---|
| AMRAAM | End Game | 6.5 | 250.0 | 38 | Continued |
| Bomb Fragment Data | Arena Tests | 0.0825 | 0.9 | 11 | Continued |
| BLU-109 | Lethality Testing | 0.0825 | 3.0 | 36 | Continued |
| Air-to-Air Missile | Lethality plus Engagement | 20.0 | 75.0 | 4 | Continued |
| Wide Area Anti-Armor Munition | Lethality Analysis | 0.75 | 30.0 | 40 | Canceled |
| Hypervelocity Missile | Lethality Analysis | 0.5 | 10.0 | 20 | Canceled |
| ISAS | Lethality Analysis | 0.75 | 40.0 | 53 | Canceled |
| Kinetic Energy Penetrator (KEP) | Lethality Analysis | 1.1 | 50.0 | 45 | Canceled |
| JP 233 Runway Attack Munition | Lethality and Vulnerability Analysis | 1.1 | 54.0 | 49 | Canceled |
| Boosted Kinetic Energy Penetrator | Runway Vulnerability Models | 2.75 | 130.0 | 47 | Canceled |
| JAVELIN ATGM | Analytic Simulation | 0.62 | 14.0 | 23 | Accepted |
| M2 Bradley FVS | Engineering Design | 0.88 | 30.0 | 34 | Accepted |
| M1A2 Vulnerability | Damage Prediction | 1.83 | 30.0 | 16 | Cost Avoidance |
| M1A2 Block 3 | Design Vulnerability | 1.76 | 100.0 | 57 | Terminated |
| Standard Missile SM-2 BLK IIIA | Cost Reduction | 2.25 | 47.0 | 21 | Accepted |
| Phalanx CIWS | Performance Evaluation | 8.12 | 125.0 | 15 | Continued |
| Phalanx CIWS | Product Upgrade | 6.63 | 200.0 | 30 | Accepted |
| AIM-7P Sea Sparrow | Lethality Analysis, End Game | 0.7 | 16.0 | 23 | Accepted |
| Phoenix Missile | Lethality Analysis, End Game | 2.23 | 70.0 | 31 | Accepted |
| ECM vs. AMRAAM | Lethality Analysis, End Game | 0.58 | 10.5 | 18 | Eval. Continues |

## 2.2 TECOM VIRTUAL PROVING GROUNDS (VPG)

For M&S to be useful and valid, the applicable tools must be based on real data derived from testing [TECOM 1995]. The Army's Test and Evaluation Command (TECOM) supports this concept with an approach known as Simulation and Modeling Anchored by Real Testing (SMART). TECOM is employing SMART as a means for researchers and developers to verify that their models and simulations are based on empirical data. VPG is a network of models and simulations, using empirical data, that enables interactive testing in a synthetic environment. A number of projects undertaken by TECOM use these models and simulations to determine the various effects on systems and to replicate actions without undertaking the time and expense of actual testing.

Table 4 represents a summary of selected TECOM systems that used VPG in conducting tests and evaluations with cost avoidance as an MOE. Actual cost includes investment in simulation when appropriate and available.

**Table 4. TECOM VPG Costs**

| Project | Use | Simulation | Actual Cost ($M) | Cost Avoidance ($M) |
|---|---|---|---|---|
| Firing Impulse Simulator | Recoil loads and ballistic shock effects | Replicate actual firing without the use of ammunition for tanks and howitzers | 6.9 | 23.0 |
| M830E1 Fuse Testing | Evaluates tank vs. helicopter engagements | Virtual test range simulation using simulated helicopter engagements with manned tank | 0.26 | 1.5 |
| Moving Target Simulator | Immersion of entire weapon system (air or ground) into moving visual target environment | Assess the ability of an M1A2 tank crew to track and simulate firing on images of simulated maneuvering targets | — | 1.5 per year |
| Simulation/Test Acceptance Facility (STAF) | Test millimeter wave radar-guided missiles | Hardware-in-the-loop simulator providing test of a "live" missile with multiple computer-based test scenarios | — | 10.6 per year |
| Aerial Cable Range (ACR) | Test missile tracking of heat sources | Uses a 3-mile long suspended Kevlar cable that serves as path for captive vehicles | 0.7 | 13.8 |
| Test Item Stimulators (TIS) | Non-radiating simulated message traffic to C3 systems | Test of Enhanced Position Location Reporting System (EPLRS) | 4.7 | 2.0 |
| Trajectory Sense and Destroy Armor Simulation (SADARM) | Model ballistic simulation for the SADARM projectile | Enables downrange auto-trackers to acquire and track incoming projectiles and transition quickly to acquire end-game data | — | 12.0 |
| Physical Simulation of Bridge Crossing | Bridge durability tests | Mix of physical and simulated bridge crossings | 0.325 | 0.11 |

## 2.3 ARMY MISSILE SYSTEMS

The Army Missile Command (USAMICOM) Research, Development and Engineering Center (RDEC) uses M&S extensively in the development of Army Missile Systems [Jolly and Ward 1995]. During the course of numerous simulation projects, the benefits of hardware-in-the-loop (HWIL) simulations have translated into cost savings and avoidance for many weapon system development programs. Examples of *cost saving and avoidance totaling in excess of $320M* are presented in Table 5.

**Table 5. Army Missile Systems Costs**

| Project | Application of HWIL and DIS Simulation | Save/Avoid ($M) |
|---|---|---|
| MLRS-TGSM | 45% reduction in flight/drop test program | 6.0 |
| FOG-M/NLOS | HWIL simulation identified all hardware and software faults prior to flight tests, resulting in reduction in flight test costs | 15.0 |
| Longbow | Successful Proof-of-Principle and EMD flight test programs with prevention of at least 2 test failures and reduction of risk in several other cases | 6.5 |
| Classified Program | Viability of this development program possible only through HWIL simulation; estimated flight test cost savings | 60.0 |
| HAWK | Flight test cost savings on counter ECM and other system improvements | 80.0 |
| STINGER | Flight test cost savings for benign, countermeasured, and untestable scenarios | > 90.0 |
| ATACMS | Analysis of flight test anomaly possible only with hardware-in-the-loop simulation; rapid identification of source of anomaly saved extensive investigation | 0.5 |
| JAVELIN | Performance assessment data for milestone 3 decision produced by simulations, avoiding several flight tests | 5.0 |
| Foreign Materiel Exploitation | ECM hardware/software/techniques evaluation and optimization against foreign threat missiles (Desert Storm payoff in identified saving of at least one aircraft and pilot) | > 25.0 |
| FAADS-BSFV (DIS) | Evaluate options using real soldiers, without requiring costly development of prototype systems, and save substantially on field testing | 32.1 |
| | **Total Cost Savings or Avoidance** | **> 320.1** |

## 2.4 APACHE LONGBOW

An example of some of the benefits of using M&S in the Apache Longbow program are summarized in Table 6 [Swinsick 1995]. Phase I of Force Development Test and Experimentation (FDT&E) was based on manned simulation. Phase II employed approximately the *same test scenario and activities* but used live equipment. *Twice as many trials were conducted in Phase I than in Phase II, at less cost, with fewer personnel, in less time.* Phase I tests allowed the helicopter crews to train on the new equipment without the risk associated with flying real equipment. It also allowed development and practice of new tactics, techniques, and procedures. Those responsible for developing scenarios for Initial Operational Test and Evaluation (IOT&E) have the opportunity to structure the very expensive operational test to gain the most critical information.

**Table 6. Apache Longbow FDT&E Tests**

| Resources | Phase I<br>Manned Simulation | Phase II<br>Field Test |
|---|---|---|
| Cost (O&M Army) | $.712M | $4.049M |
| Equipment | 1 Simulator | 4 AH-64D<br>2 UH-60<br>14 M1 Tanks<br>10 M3 Fighting Vehicles<br>2 2S6<br>20 + Air Defense Units<br>47 + Vehicles |
| Personnel (Government) | 27 | 663 |
| Mission Turn-Around Time | 2 Hours | 6 Hours |
| Data Reduction Time | 4 Hours | 80 Hours |
| Number of Trials | 32 | 16 |
| Test Period | 4 Weeks | 6 Weeks |
| Safety | No Risk | Moderate Risk |

# 3. TRAINING APPLICATIONS OF M&S

## 3.1 INDIVIDUAL SKILLS TRAINING

Individual training is supported most often by *stand-alone simulators*. These simulators range from simple devices (such as rifle marksmanship trainers) to more complex devices (such as maintenance simulators, tank gunnery simulators, and flight simulators). Simpson et al. [1995] drew these general conclusions about the effectiveness and cost of such simulators:

> ...in aggregate, simulators provide significant beneficial transfer from simulator to aircraft at a median operating cost of about one-tenth of an aircraft...Because of their scope, the body of studies probably provides the strongest case for the value of *any* type of simulation.
>
> Students trained using maintenance simulators perform about as well as those trained with actual equipment, but simulators cost a fraction...of the equipment...where time to train was reported, training with simulators took...less time than with actual equipment.

### 3.1.1 Aviation

The Army estimates that it substitutes simulation for $68M of flight operations training in the active force and $55M in the Reserves each year. The Navy considers simulation to be effective in initial training in unfamiliar aircraft, as is reflected in the ratio of simulator to actual aircraft training flights (40 to 77) in the fleet replacement training program for F/A-18 aircraft. The Air Force Air Mobility Command plans to replace up to 50% of flight training hours with flight simulators and other training devices for training air transport crews [Orlansky et al. 1994; Department of the Army 1993].

The operating cost of flight simulators is estimated to be between 5 to 20% that of aircraft. Many studies have shown that skills learned in flight simulators can be performed successfully in aircraft, and the use of simulators for training can reduce flight time [Orlansky and String 1977]. In a more recent study, the median cost ratio of operating simulators to aircraft was estimated to be 8% [Orlansky et al. 1984].

A review of several studies showed that the operating costs of flight simulators are about 10% of actual equipment per hour trained or 33% if acquisition cost is taken into account. The majority of tasks trained on simulators (59%) have significant positive transfer to flight performance [Angier et al. 1993].

Bombing and air drop accuracy data indicate that additional simulator hours seem to have a greater positive effect than additional flying hours, and simulator hours cost at most a third as much. Helicopter accident data indicate that both flying hours and simulator hours reduce accidents, but simulator hours do not increase exposure to risk [Horowitz et al. 1992].

### 3.1.2 Small Arms

Several studies relating to the use of simulation in lieu of live fire indicate that performance with simulation is at least equal to live fire training, but that cost is lower. Soldiers with MACS (Multipurpose Arcade Combat Simulator) training expended less rounds during live-fire qualifications and fewer soldiers failed to qualify as compared to those trained using traditional methods. Several studies with the Squad Engagement Training System (SETS) have shown positive transfer from SETS to live fire. Training with the Indoor Simulated Marksmanship Trainer (ISMT) has been demonstrated to benefit live-fire performance. The Precision Gunnery Training System (PGTS), an inexpensive trainer for TOW and DRAGON missiles, whose rounds are very expensive ($11,500 and $19,145, respectively, per round), has been demonstrated to be cost effective, and also permits training that would otherwise cost several hundred million dollars per year if actual missiles were used [Bailey and Hodak 1994; Wilhoite 1993; Eisley et al. 1990; Schendel et al. 1984; Berg et al. 1993b].

### 3.1.3 Maintenance

A review of maintenance simulators found that they are as effective for training as actual equipment trainers when measured by student achievement in school. In the majority of cases examined, the cost to develop and fabricate one unit was less than 60% of actual equipment and the cost of fabricating a second unit was less than 20%. Acquisition and use of a maintenance simulator over a 15-year period cost 38% as much as the actual equipment. In studies where time to train was reported, simulators took 25 to 50% less time than actual equipment [Orlansky and String 1981].

### 3.2 COLLECTIVE SKILLS TRAINING

Collective training focuses on tasks performed collectively by groups of individuals (e.g., crews, teams, units) who must work together and coordinate their activities. The size of a collective may vary greatly and hence collective training varies considerably in scale. It is supported most commonly by *live* or *virtual* simulation. Some *stand-alone simulators* train smaller personnel collectives (e.g., flight crews, tank crews). *Advanced distributed simulation*—a set of varied models or simulations operating in a common synthetic environment composed of live, virtual, and/or constructive simulations—can also be used for collective training. A recent analysis by the General Accounting Office (GAO) [GAO 1993] conducted for Congress cited as exemplary several simulations used by the Army for collective training: COFT (Conduct of Fire Trainer), used on tanks and Bradley Fighting Vehicles; MILES (Multiple Integrated Laser Engagement System), used to simulate direct fire weapons from rifles to tank and helicopter gunnery systems; and SIMNET (simulator networking), used to provide crew-, platoon-, and company-level training. A 1994 review of technologies supporting virtual simulation indicated that it is becoming increasingly powerful and cost effective [OTA 1994].

#### 3.2.1 Crew/Team

Evaluations of the UCOFT (Unit Conduct of Fire Trainer) have been positive. Tank gunners trained with UCOFT fire their opening rounds about 25% faster than conventionally trained gunners. Based on an analysis of a hypothetical force-on-force engagement, UCOFT-trained gunners would be expected to kill significantly more opposing tanks than conventionally trained gunners [Operational Research and Analysis Establishment 1990]. Boldovici et al. [1985] reviewed UCOFT tests and concluded that UCOFT provides improvements in gunner proficiency. Substantial gains were found in percents of targets acquired, engaged, hit, and killed for groups undergoing sustainment and transition training. Gains were attributed to improvements in acquisition time, engagement time, and first-round hits, which in turn allowed time to scan, acquire, and engage available second and third targets. Hughes et al. [1988] evaluated the training effectiveness of the UCOFT empirically with 369 tank commander-gunner pairs and found that UCOFT training accelerated skill acquisition, improved performance in subsequent training events, and was well accepted by users.

In tank gunnery, the introduction of COFT reduced the annual expenditure of ammunition from 134 to 100 rounds per tank and improved marksmanship. This resulted in an annual cost avoidance of approximately $29M. The new Tank Weapons Gunnery Simulation System is expected to reduce the annual consumption to 78 rounds, for an additional saving of $21M to $50M each year [Orlansky et al. 1994; Department of the Army 1993; Morrison et al. 1991a, 1991b; Turnage and Bliss 1990].

### 3.2.2 Multiship Air Combat

In evaluations of developmental distributed interactive simulation (DIS) systems designed to support multiship air combat training in a combat engagement simulation environment, participating pilots and air weapons controllers indicated that simulation enhanced their combat readiness and was more beneficial in some areas than traditional unit training [Bell and Crane 1992; Houck et al. 1991].

In evaluations of a SIMNET-compatible air combat simulator, pilots received training and then rated their interest in receiving additional training on each of 30 tasks. Tasks with the highest rated interest can usually be practiced only in large exercises or cannot be practiced except in simulation. It was concluded that multiplayer simulator-based training is a valuable training medium for increasing wartime readiness, especially for less experienced pilots [Crane and Berger 1993].

### 3.2.3 Tactical Ground Combat

During the Persian Gulf War, at the battle of "73 Easting," U.S. troops destroyed an opposing force three times their size while fighting in an area the Iraqis had previously used for training exercises. Leaders of the U.S. force cited the training they had received with live simulation, virtual simulation, and stand-alone crew training simulators as important factors in their success [Orlansky 1993].

The Army Science Board [1989] has estimated that simulators would enable a reduction in aviation and vehicle OPTEMPO (Operating Tempo) and training ammunition by 15 to 20% while maintaining the same or better level of unit performance.

A series of tests and evaluations have demonstrated SIMNET's value for collective training. Schwab and Gound [1986] evaluated SIMNET's capability to support platoon-level command and control exercises to train individual and collective tasks. The eight platoons were divided into two groups, one with prior SIMNET training and the other without. Three of the four platoons in each group improved their performance between the first and second set of situational training exercises. The SIMNET group improved its average group score by 13% while the baseline group improved its score by 6%. Findings of Kraemer and Bessemer [1987] suggest that SIMNET training helped units develop and improve their fire control distribution plans and helped unit leaders develop the command, control, and communications skills to effectively execute those plans during platoon battle runs. Brown et al. [1988] found that SIMNET training increased field exercise platoon performance, command and control, and leadership skills, and adequately portrayed vehicle and battlefield sounds. SIMNET also improved performance of command and control, platoon movement, leadership, and fire distribution during the company team Army Training and Evaluation Program (ARTEP). Burnside [1990] found that 35% of ARTEP Mission Training Plan (MTP) tasks can be trained with SIMNET. Bessemer [1991] found positive transfer of tactical training from SIMNET to field training. Analysis of an effectiveness comparison between SIMNET and home-station field training indicates that SIMNET is extremely effective in increasing performance for SIMNET-trainable tasks relative to field training. Tradeoff analyses show that investment in SIMNET-like facilities could be repaid by an 8 to 14% decrease in OPTEMPO [Angier et al. 1993].

An analysis of the training capabilities and cost effectiveness of the Close Combat Tactical Trainer (CCTT) concluded that it has the potential to train tasks relating to command, control, and communications; maneuver and navigation; and teamwork and leadership. When fielded, CCTT would be cost effective and its life cycle costs would be paid back fully during its service life [Noble and Johnson 1991].

### 3.2.4 Multi-Service and Joint Training

The Army Research Institute for the Behavioral and Social Sciences (ARI) has successfully demonstrated the use of virtual simulation for multi-Service close air support training and is currently expanding its demonstration platform to include the Joint fire support mission [ARI 1995a, 1995b; Hawley and Christ, in press].

Virtual simulation has the potential to enable Joint and inter-Service training in mission areas not being trained sufficiently now (e.g., close air support). The technology permits coordinated training among the Services while individual Service elements remain at their home stations [Simpson et al. 1995].

## 3.3 COMMAND AND STAFF TRAINING

Command and staff training occurs within constructive, live, and/or virtual simulations. The participating commanders and staffs range from the lowest to the highest echelon and from a single Service up through Multi-Service, Joint, and Combined commands. The most economical way to conduct such training is with constructive simulations, as they enable commanders and staffs to experiment without the cost of fuel, ammunition, and military personnel. Command and staff training does occur during live and virtual simulations, but usually these simulations are intended to train all participants at all levels. Because of their economy and relative ease of implementation, constructive simulations have proliferated in many different training domains.

### 3.3.1 Single-Service Training

The 1990 REFORGER (Return of Forces to Germany) exercise made extensive use of constructive simulation to train leaders at brigade, division, and corps level. Benefits of such training were the emphasis on battle planning, staff procedures, and command and control; more efficient use of training time; focus on higher echelons that would otherwise be cost prohibitive; and reduced adverse environmental and political impacts. The transportation and cargo handling costs of the 1990 exercise were more than $4M less than costs historically [GAO 1991]. In 1992, constructive simulation was used to avoid $34M in costs as compared with the equivalent exercise done without simulation in 1988. Participants also believed that the training of staffs and planners involved was improved [Simpson et al. 1995]. However, previous REFORGER exercises satisfied a treaty obligation to return forces to Germany, and they provided extensive training to those responsible for physical movement of troops and equipment.

GAO noted that at the brigade level and above, simulations can be used to improve the decision-making skills of senior battle officers before they command units in large-scale training exercises [GAO 1993].

Formal evaluations have demonstrated that constructive simulations train commanders and staffs effectively and are relatively inexpensive. The JANUS(A) is effective in training company level officers and platoon leaders on current tactics and doctrine. The Brigade/Battalion Battle Simulation (BBS) has proven effective at training brigade and battalion staffs [Bryant et al. 1992].

### 3.3.2 Multi-Service and Joint Training

The Defense Science Board [1988] concluded that computer-based simulated scenarios offer the *only* practical and affordable means to improve the training of Service operational commanders, their staffs, and the commanders and staffs who report to them. Battle simulation offers the only opportunity to practice the use of certain weapon systems, sensors, tactics, and techniques against a skilled adversary.

Agile Provider (AP), a Joint exercise sponsored by the United States Atlantic Command (USACOM), replaced Unified Endeavor (UE) in 1995. AP was a field exercise last held in 1994. UE was supported by a Joint Training Confederation (JTC) of models interacting through the Aggregate Level Simulation Protocol (ALSP). The models replaced steaming days and flying hours, and focused on the primary training audience, the JTF commander and staff. Total costs for AP-94 were $40M, with $8M in strategic lift costs. UE-95's costs totaled $2.9M with approximately $0.5M in strategic lift. Approximately 85% of the UE-95 participants rated their training as good and 82% rated it better than a similar field exercise like AP-94. The conclusion was better training at 7.5% of the cost.

# 4. ANALYSIS APPLICATIONS OF M&S

M&S contributes to innumerable decisions involving system evaluation and force sizing. In addition, it contributes significantly to combat operations. In 1990 and 1991, the Air Force Studies and Analyses Agency (AFSAA) performed a series of Gulf War analyses that Lieutenant General Glosson (then chief of Central Air Forces Special Projects) asserted "...saved literally hundreds of lives" [Case 1991].

A team of AFSAA analysts was quickly deployed to the Air Force Operations Center in Riyadh, Saudi Arabia, where they analyzed the air campaign both before and after it began. For their analyses, they used primarily the Army's Space and Strategic Defense Command's Extended Air Defense Simulation (EADSIM) (also called the C3ISIM) model.

At the time, EADSIM was a new model to AFSAA and had been selected because it did an excellent job of analyzing command, control, and communications. It was a hybrid model with Monte Carlo and deterministic features. The combat operations planners were able to watch a preview of the attack as it unfolded in a way that graphically revealed the plan's strengths and weaknesses. Unlike the actual air defenses, the modeled air defenses acted in a rational manner, with the simulation results showing a worst case scenario for the actual air assault.

One main contribution was to choreograph the masses of aircraft into and out of the Kuwaiti Theater of Operations. To ensure that aerial tankers would make their rendezvous with fighters in need of refueling, missions were played out in advance. Attacks were carefully choreographed to avoid mid-air collisions, especially during the first day's intense activity.

Planners also analyzed the best use of defense suppression assets, and alerted planners of missions that were too hazardous for some aircraft. For instance, the AFSAA team analyses indicated that it would be too dangerous to carry out plans to send A-6 and Tornado aircraft directly over Baghdad. As a result, only F-117 stealth fighters (none of which was lost) were assigned targets in this highly defended area. Undoubtedly, these changes saved allied lives and the needless loss of aircraft. When planners determined that Scud sites in Western Iraq were too well defended and (as existing prior to the attack) too hazardous for F-15E attacks, defense suppression missions were reconfigured to correct the problem. When aircraft losses did occur, computer simulations were used to help determine the most likely cause so that later missions could be made less dangerous.

# APPENDIX A. MEASURES OF EFFECTIVENESS

## A.1 INTRODUCTION

### A.1.1 Problem Statement

DMSO has articulated a need for assessing the effect of M&S on the full range of DoD activities. The effect is difficult to quantify for several reasons: acceptable effectiveness metrics are lacking, supporting data are difficult to unearth, and in some cases it is not possible to identify a baseline from which to measure.

One member of the Task Force[1] examined 30 programs to determine how users of M&S measured their success. Those programs are listed and summarized in the Attachment after the exposition of findings. A second member of the Task Force presented a complementary discussion, contained in Appendix B, showing alternative methods of calculating cost effectiveness and a range of effectiveness measures and cost components.

To measure the effect of the many M&S applications in the DoD, we must first state our objectives in quantifiable terms. Only then can we assess our progress toward reaching those objectives. The metrics described here are nominated for comment, and will move us toward measuring the effects of M&S.

### A.1.2 Technical Areas, Functional Areas, and DoD M&S Objectives

M&S capabilities fall into one of two broad areas. The Technical Areas deals with mechanisms that make the M&S application work, while the Functional Areas considers how the M&S application will be used. The two broad areas, their subareas, and the DoD M&S objectives are discussed in the following list, along with a short description of the M&S objectives.

- Technical Areas. As mentioned above, this area deals with the inner workings of the M&S tool. The particular topics in this area are as follow:

  Architecture: The high-level system and software design of the M&S tool.

  Computer Generated Forces (CGF): The representation of constructive simulations.

[1] Mr. Matt Aylward of MITRE, Quantico, VA.

Environmental Representation: How the real world is portrayed in the synthetic environment; the effects of weather, terrain, obscurants, and their interaction with the exercise entities.

Information/Database: Methods for M&S tools to store or access information; data modeling.

Interoperability: How various M&S tools interface and operate together.

Networking: How information is shared among physically remote M&S tools.

Verification, Validation & Accreditation (VV&A): the process of giving M&S tools an official stamp of approval.

Instrumentation: Details of the infrastructure needed to incorporate live entities into the synthetic environment; the hardware and software that allows real personnel and platforms to send their state variables between M&S tools, typically through electronic messages.

- Functional Areas. M&S tools are used in the following ways:

Analysis: To conduct experiments where useful information can be extracted.

Training: To enhance military readiness through training, mission planning, and mission rehearsal.

Acquisition (research and development): To allow virtual prototyping, enhance brainstorming, and expand the number of design options that can be considered.

Acquisition (test and evaluation): To accomplish both Developmental Testing (DT) and Operational Testing (OT). Breadboards and brassboards, combined with stimulation from M&S tools, enhance the quality of DT and OT results.

Acquisition (production and logistics): To support design, manufacturing, process analysis, and support planning.

- Master Plan Objectives.

The *Department of Defense Modeling and Simulation Master Plan* [DMSO 1995] lists objectives that M&S tools should achieve. The relevant objectives—framework, environmental representation, systems representation, and human behavior representation—are closely related to the preceding sections on Technical and Functional Areas. Accordingly, a separate discussion of each M&S application area is unnecessary.

## A.2 OBSERVATIONS FROM 30 CASE STUDIES

### A.2.1 The Search for Metrics

To capture the benefits of any investment, there must be agreement upon objective standards to measure the performance of a particular investment. This appendix contains a proposed set, with quantitative and qualitative metrics. The projects listed in this appendix were selected to demonstrate the breadth of M&S benefits enjoyed by DoD. A discussion of the candidate quantitative and qualitative metrics follows.

### A.2.2 Quantitative Metrics: Technical Areas

- Architecture: Decisions about programming architecture have far reaching consequences. Not only are current and future M&S tools affected, legacy systems will also feel some effect. The metric in this area, *Percent of Legacy Migration*, reflects this effect. An underlying Measure of Performance (MOP) to this metric may be the amount of effort (measured in staff-years or dollars) required to migrate a legacy system to the proposed architecture.

- Computer Generated Forces (CGF): Modular Semi-Automated Forces (ModSAF) is the current DIS-compatible software for generating personnel- and vehicle-level entities. M&S tools featuring highly detailed constructive simulation of combat at the lowest level rely on this software. War games also use CGF but usually at a higher level of aggregation. Following the same rationale developed for Architecture, the candidate metric is *Percentage of Software Reused.*

- Environmental Representation: The candidate metric, *Stimulations*, reflects the role of the environment in the real world. Military personnel constantly adjust their plans according to the current or future environment conditions, sorties are canceled or diverted due to obscurants over the primary target, or offensive operations are delayed because the main supply route is a sea of mud. This metric can be measured in many ways. For example, how many environmental effects can the M&S application portray? How many variables does the application use to describe the water column near the landing beach? So, within the metric of *Stimulation*, a number of MOPs can be developed for a given M&S application.

- Human-Systems Interface: There are quantitatively rigorous techniques for measuring how well a M&S application approximates the real system; accordingly, the candidate metric is *User Acceptance*.

- Information/Database: Ready access to information, especially information stored in databases, is critical to reducing the overhead of M&S tools. As future tools will rely on information archived in databases of various designs, database design decisions should consider migrating legacy databases. Possible metrics include *Level of Effort Required for Collaboration* and *Reuse*, measured in staff-years and cost avoidance, perhaps arising from the reuse of an existing database.

- Networking: The links connecting the various sites involved in a DIS exercise are vital for exercise success. When choosing among various network designs, the analysis should identify the least expensive choice that ensures a successful DIS exercise. Therefore, possible metrics are *Cost per Megabit per second* and *Latency*.

- Verification, Validation, and Accreditation (VV&A): If there is a suitable M&S application in existence, and this application has undergone a formal VV&A process, then a particular project has no reason to create a new application. Developing a rigorous VV&A procedure, particularly one that is not onerous to the owners of M&S tools, would enhance software reuse; accordingly, a candidate metric is *Cost Avoidance*, arising from such reuse.

- Instrumentation: When conducting instrumented exercises, the Services can completely forgo live fire or use the position reporting capability to have positive location information on each player. In either case, the risk of fratricide or erroneous fire mission approval by the Fire Support Coordination Center is greatly diminished. Consequently, a candidate metric is *Risk Reduction*.

### A.2.3 Quantitative Metrics: Functional Areas

- Analysis: Current evaluations of military operations rely heavily on anecdotal information; if analysts had a mechanism to capture what really happened, the resulting conclusions could have a much smaller confidence interval. An assessment of how various proposed M&S tools allow the analyst to better understand a process, and perhaps conduct the analysis from "ground truth," would be of obvious interest. One candidate metric for this assessment is *Net Utility*.

- Training: By far the functional area to benefit the most from M&S tools, training also has the most easily defined metrics. Examples include *Cost Savings*, *Cost Avoidance*, and *Risk Reduction*; for example, it is hard to have a fatal mishap in an F/A-18 simulator.

- Acquisition (research and development): Candidate metrics include *Cost Savings*, due to avoidance of premature fabrication, and *Number of Options Considered*. The second metric for research and development (R&D) and production and logistics (P&L) captures the same idea: Study a wide range of options for the proposed system in virtual reality before making the first bend in metal.

- Acquisition (test and evaluation): A number of case studies show that using M&S tools to prepare for DT and OT is advantageous. M&S allows for better designed tests, aids in training the test force, and identifies areas of deficient data collection. In some cases, such as testing software upgrades for the F-14, M&S is the only way to conduct DT, due to the risks involved. Use of *Cost Avoidance* as a metric is well supported by these case studies.

- Acquisition (production and logistics): Candidate metrics include *Cost Savings* and *Number of Options Considered*. The former accrues when production lines and consumption rates can be simulated, allowing problem identification and correction before the system is fielded. The latter is appropriate when application of M&S allows planners to explore a wide range of production options in detail, at a minimal cost, when compared to exploring the options with real-world equipment.

### A.2.4 Qualitative Metrics: Technical Areas

- Computer Generated Forces (CGF): The more realistic the portrayal by the CGF, the better the training; therefore, a candidate metric is *Training Quality*, as evaluated by the training audience.

- Environmental Representation: One candidate metric is *Immersion*, a measure of how "real" the environment feels to the trainee.

- Human-Systems Interface: How well the M&S application matches the feel of the simulated system is critical to positive training transfer. For this reason, a candidate metric is *Ease of Use*, as evaluated by the trainee or instructor.

- Interoperability: Ideally, all Service models would interoperate readily, thus ensuring that the conclusions of a study sponsored by one Service would be acceptable to all Services. For example, the Office of the Secretary of Defense (OSD) can choose among a number of combat simulations to evaluate Service roles and missions; the selected simulation should neither over- nor understate the relative value of any one Service. A candidate metric, *Level Playing Field*, embodies this idea of a neutral evaluation tool.

- Networking: If the M&S application is distributed, the network can either degrade or enhance the sensory experience of the participants. The quality of sensory stimulation, the feeling of *Immersion* experience by players, is a candidate metric.

- Verification, Validation, and Accreditation (VV&A): The candidate metric is *Enhanced Decision Support.* Here, the implicit assumption is extended one step further: A model that has completed a formal VV&A process produces results that are "more valid" than results from a non-VV&A process. "More valid" results will lead to better quality decisions.

- Instrumentation: With many M&S tools executing over current command, control, communications, computer, and intelligence (C4I) systems, it is desirable for these two disciplines to merge. A candidate metric is *Merger of C4I with M&S.* This metric estimates how closely a particular M&S application approaches this goal.

### A.2.5 Qualitative Metrics: Functional Areas

- Analysis: As discussed in the quantitative section, much analysis of military operations is based on anecdotal data. Merging live, virtual, and constructive simulations with C4I systems would give analysts much better quality data with which to work. For these reasons the metric, *Data Quality*, is offered.

- Training: The candidate metrics are *Readiness* and *Unique Training. Readiness* is enhanced because the lower cost of training with M&S tools increases the quantity and quality of training opportunities. *Unique Training* is possible with M&S because only electrons are in danger of getting killed. This metric speaks to the ability of M&S to present trainees with situations not seen in the real world outside of combat.

- Acquisition (research and development): The candidate metrics are *Brainstorming* and *Unique Capability. Brainstorming* refers to the ability of M&S to let program managers explore a much wider array of options before settling on one approach. In other cases, the *Unique Capability* of M&S cannot be reproduced in the real world.

- Acquisition (test and evaluation): Possible metrics include *Developmental Test Planning, Operational Test Planning, Development of Measures of Performance (MOP),* and *Development of Measures of Effectiveness (MOE).* These metrics assess how well an M&S tool assists the test and evaluation community in all of the foregoing tasks.

# ATTACHMENT TO APPENDIX A

**Projects Examined for Measures of Effectiveness**

1. Indoor Simulated Marksmanship Trainer (ISMT): A stand-alone M&S application, ISMT is used for training Marines in all aspects of small arms fire, as well as training small units in tactical engagements. Analysis indicates that use of the ISMT for a portion of annual weapons requalification could save significant amounts of money as a result of ammunition offset [Fish 1995a].

2. Deployable Forward Observer - Modular Universal Laser Equipment (DFO-MULE): A stand-alone M&S application, DFO-MULE is a training device for forward observers (artillery and mortar) and forward air controllers. It complies with current DIS standards. The DFO-MULE is being used in the Multi-Service Distributed Testbed. A MITRE analysis indicated that use of the DFO-MULE for required forward observer training could save significant amounts of money as a result of ammunition offset [Fish 1995c]. Assuming a 10% offset in live fire tasks, savings in ammunition expenditures could recover the acquisition costs before the end of the second year.

3. Emerald Light: A Marine Corps proof-of-concept demonstration, Emerald Light will instrument a training range at the Marine Corps Air Ground Combat Center (MCAGCC) at 29 Palms, CA. Ultimately, the MCAGCC and the National Training Center (NTC) at Fort Irwin, CA, will be linked. This will allow the conduct of Joint exercises at both sites. During the exercise, participants will share a synthetic battlespace over the Defense Simulation Internet (DSI).

4. Synthetic Theater of War - Europe (STOW-E): A Defense Advanced Research Projects Agency (DARPA) funded effort, STOW-E allowed the Army to link live, virtual, and constructive simulations to conduct a large-scale training event embedded within ATLANTIC RESOLVE. Comparable in breadth to REFORGER (Return of Forces to Germany), ATLANTIC RESOLVE cost on the order of $37 million less to conduct than REFORGER.

5. LeatherNet: A DARPA-funded project developed in concert with STOW-97, LeatherNet seeks to create a credible Marine Corps CGF at the level of the individual rifleman.

6. Turret Layout: Not really a project as much as a study, the Turret Layout effort compared the use of M&S to prototype construction for developing modifications to the Abrams tank. The M&S application allowed more options to be considered, at a lower cost, in less time, while involving the user community; the benefits were clear cut and convincing.

7. Advanced Medium Range Air to Air Missile (AMRAAM): During the development of this system, investments in M&S tools allowed engineers to fly a complete mission profile in a virtual environment. The amount and quality of data made available from this investment far exceeded the telemetry from a real flight. Also, given the cost of each flight and the number of flights required, actual flight testing was prohibitively expensive. Only M&S could satisfy the need for performance data at an acceptable cost.

8. AIM-9X: The AIM-9X missile is an implementation of advanced medium range air-to-air missile technology. See discussion of the AMRAAM (7).

9. F-14 Software Test: The F-14, like most modern aircraft, relies on computers to execute its mission. Changes to its software are made continuously, yet each change could potentially result in non-desirable flight performance such as crashes. For this reason, each change in software must be rigorously tested before the plane is flown. This testing must be conducted on the ground, with all flight control systems receiving accurate input stimulation. Only M&S tools can provide this input. In the absence of simulation, upgrades to the F-14 software would not be possible.

10. Advanced Amphibious Assault Vehicle (AAAV): While this program is moving forward under the conventional acquisition paradigm, it is concurrently looking at ways to use M&S tools to change the process. One example is the participation of the two automotive test rigs participating in the Virtual Proving Ground. In this project, data collected from real vehicles on the test track at Aberdeen Proving Grounds are compared to data produced by computer simulations. Successful completion of the Virtual Proving Ground project will give designers the ability to consider many design options without bending any metal.

11. Boeing 777: During the development of this aircraft, the Boeing Corporation re-invented itself: this is the world's first paper-less airplane. Boeing's corporate information system architecture allowed for extensive use of CAD, CAE, and CAM (computer-aided design, engineering, and manufacturing). Production of the aircraft was greatly simplified, as only a minuscule amount of time was lost to poorly fitting parts. In turn, this reduced the costs of production by reducing labor overtime charges and scrap rework.

12. New SSN Prototype: Employing simulation (see Boeing 777, (*11*)) for the follow-on to the SSN-21 (Sea Wolf class), General Dynamics has already experienced cost avoidance on the order of tens of millions of dollars. Proposed changes to the weapon systems consoles, sensor suites, or engineering plant can be completely explored in a virtual environment before any metal is bent. Compared to previous construction methods, large costs are avoided. This is an example of how the corporate information system architecture can have a significant effect on the bottom line.

13. B-2 Mockup: In a vein similar to Boeing and General Dynamics, Northrop designed its CISA to gather information throughout the company. As a result, the mockup of the B-2 was so close to the design resident in the CISA that future mockups may be eliminated entirely.

14. SEEK IGLOO: An Air Force project to deploy warning radar, SEEK IGLOO's concept of employment called for manned installations. A MITRE simulation determined that the radar was much more reliable than assumed. This led to a different concept of employment, unmanned radar installations of smaller size. Large savings from cost avoidance were realized.

15. F-16 Operational Test (OT) Scenario Development: By using simulators, the OT project officer was able to realize a number of benefits. First, the test team was fully trained in the scenario for the OT, increasing the efficiency of the test. Second, the test crews were able to show the project officer what performance measures were truly important, leading to a modification of the test scenario. In this way, simulation led to a higher quality OT.

16. Forward Area Air Defense System/Air Defense, Anti-Tank System (FAADS/ADATS) Measure of Performance (MOP): Since neither of these systems exist, the project officer was stymied in attempts to develop appropriate MOPs. The use of simulation allowed the project officer to clarify the concept of employment and develop worthwhile MOPs.

17. Non Line of Sight (NLOS) Operational Test: The NLOS is a new type of anti-tank weapon that allows for precision attack of armored vehicles by a gunner in full defilade. Facing problems similar to the FAADS/ADATS (*16*), the project officer turned to simulation. Again, the existence of sophisticated M&S tools led to high quality OT of a future system.

18. Virtual Proving Ground: This is an effort between the Army's Aberdeen Proving Grounds, Aberdeen, MD, and the University of Iowa. It is an attempt to create a synthetic environment for testing vehicles. The goal is to allow engineers to fully explore system design (e.g., of the HMMWV) before any metal is bent.

19. Joint Warfare Concept Analysis - Operations Research (JWCA-OR): JWCA-OR is an effort to improve the quality of Joint analysis. For this work, it is essential that all Services are represented, as JWCA-OR supports force structure decisions, aids in developing Joint doctrine, and guides force allocation to the warfighting commands. Currently, Service representation largely involves legacy systems.

20. Joint Warrior Interoperability Demonstration (JWID): JWID is a series of demonstrations sponsored by the Chairman, Joint Chiefs of Staff. They are primarily concerned with C4I; future demonstrations will see further integration of M&S with C4I.

21. Standard Interchange Format (SIF): Developed by the Institute for Simulation and Training (IST), Orlando, FL, SIF allows existing databases to interface with M&S tools. The use of SIF generates savings for each project by reducing the number of years normally required to develop a custom interface.

22. B-52 Data Study: Undertaken by the Strategic Air Command (SAC) during Operation Desert Shield/Desert Storm, this effort collected a wide array of operational data from the bomber force. This data is potentially very useful for a number of different M&S functional uses.

23. Jedi Knights: A colloquialism that refers to a group of Army officers who provided operations research support to the Commander in Chief, U.S. Central Command (CINCCENT), in theater. Drawn from the Command and General Staff College, the members of this group were experts in the TACWAR model. Prior to the start of Operation Desert Storm, the Jedi Knights ran TACWAR manually and compared the results to the computer results from the same scenario. They judged the TACWAR output credible and proceeded to use TACWAR for operational support. The Jedi Knights are an example of the effort and benefits associated with VV&A of simulations.

24. Desert Storm Operations Research: CINCCENT, as well as subordinate commanders, made extensive use of operations research personnel as plans for Operation Desert Storm were developed or executed. Analytic support was provided from the United States, as well as from Operation Research (OR) cells in theater. Plans were developed, analyzed, and modified in a greatly truncated cycle. Without sophisticated M&S tools, the OR cells would have been unable to respond to the needs of the operational commanders. The benefit of simulation was especially evident in planning and conducting the air campaign.

25. Joint Surveillance Target Acquisition Radar Terminal Emulation (JSTAR TE): Originally intended as an adjunct to the JSTAR program, the JSTAR TE allowed the JSTAR to reach operational capability in time for Desert Storm, six years ahead of schedule. This was a great success, both for the war effort as well as for the program.

26. Defense Information Systems Agency (DISA): DISA is responsible for developing the communication links necessary to connect the far flung activities of the DoD. In this task, DISA has used a number of M&S tools to consider various alternative methods of linking the DoD nodes. There are several documented instances of cost avoidance that are the direct result of using M&S.

27. Simulation Utility Management System (SUMS): SUMS is an Air Force effort to develop an M&S tool to assess the effects of changing manpower policies and programs. It also allows personnel planners to consider various scenarios regarding the nature of the civilian labor pool.

28. Virtual Medicine: This project is still in the basic research phase, but it offers tantalizing benefits. Battlefield surgeons could operate without subjecting the wounded to the trauma of transportation to a field hospital. This multiplies the effectiveness of each surgeon, while reducing demands on the transportation system and eliminating a lucrative rear area target, the large field hospital.

# APPENDIX B. METHODS OF ANALYSIS

One member of the Task Force gathered examples of data and cost-effectiveness analysis with which she was familiar.[2] Through three case studies, she depicted alternative methods of calculating cost effectiveness using the same data. Subsequently, she generalized her observations and discussed a range of effectiveness measures and cost components, contained in this appendix. The sections covered in this appendix are as follows:

B.1 Alternative Calculations for Three Case Studies

B.1.1 AMRAAM Hardware in the Loop

B.1.2 F/A-18 Weapons Software Support Facility (WSSF)

B.1.3 Kernel Blitz

B.2 Is Cost Savings the Best Measure of M&S Effectiveness?

B.3 Candidate Measures of Effectiveness

B.4 Identification of Expenditures

[2] Ms. Michelle Bailey of Naval Air Warfare Center, Weapons Division (NAWCWD), China Lake, CA.

## B.1 ALTERNATIVE CALCULATIONS FOR THREE CASE STUDIES

The separate case studies were chosen because of the availability of data to the author and their ability to demonstrate the various methods of analysis. The data come from, or have been examined by, personnel associated with the relevant programs. Four different methods of calculating cost effectiveness are shown, each providing a different result.

- The first and most common method calculates cost savings or avoidance, and is usually based on the assumption that live and simulated events are completely interchangeable.
- The second method is break-even analysis that determines how many live events must be replaced by simulated events to recover capital investment and operating costs in a given period of time.
- The third method is based on the assumption that finding errors early in the acquisition process is less costly to repair than finding them later in the process.
- The final method of comparing alternative events is to compare their costs and their effectiveness separately. While it is the most general method, it is also difficult to implement due to the inability to adequately measure the effectiveness of an event. This final method would allow comparison of an alternative M&S-supported event with a baseline event where the alternative was more costly but provided better training, for example. Military experts could then decide whether the training increment or decrement was worth the additional, or conversely, lower cost.

### B.1.1 AMRAAM Hardware in the Loop

The AMRAAM Hardware-in-the-Loop (HIL) facility at Point Mugu, CA, is employed in the ongoing evaluation of missile guidance and control system performance. The facility includes a flight simulator table, anechoic chamber, target simulators, special interface hardware, and an instrumented missile. The facility can be used for additional applications, but only its use for testing the AMRAAM is considered here. Its primary cost components are shown in Table B-1.

**Table B-1. AMRAAM HIL Costs**

| | |
|---|---|
| BRAC Replacement Cost[3] | $23.7 M |
| Yearly Operating Cost | $930K ($1M) |
| Number of Tests per Year | 8,400 |

Using the assumption that all firings are live, we calculate an extremely favorable cost savings, as shown in Table B-2. While 8,400 *simulated* firings per year are possible, a program simply could not afford 8,400 *live* firings. Even so, several M&S cost savings we have gathered have been calculated using this type of assumption.

**Table B-2. AMRAAM Example Savings Calculations**

| Cost Savings Method (assumes all live firings) | |
|---|---|
| Cost per firing | $40K |
| Cost of missile | + $250K |
| Total cost per firing | $290K |
| Number of tests | × 8,400 |
| Total savings | $2,436M |
| Could a program do 8,400 firings, let alone in one year? | |

For this case, break-even analysis may be more meaningful. An example is shown in Table B-3. In this case, recovery of BRAC replacement costs occurs in 10 years, assuming that 12 firings per year are simulated, a far more reasonable assumption. Further, assuming 3 or 4 firings per year beyond the 10-year break-even point will recoup facility operations and maintenance costs. The conclusion, then, is that 12 firings per year will recoup the capital investment in 10 years, and the other 8,388 simulated firings are value added, i.e., contribute more effectiveness. It must be remembered that an AMRAAM missile costs considerably more during its development and early production. Consolidation of the earlier missile costs with later production costs would shorten the payback time.

3 Base Realignment and Closure (BRAC) replacement costs represent the cost to replace a facility and not the cost of original development and maintenance. This metric is used here because it is a certified figure with a definite meaning applied uniformly across the country.

**Table B-3. AMRAAM Example Break-Even Calculations**

| Time to Break-Even Method |
|---|
| • Number of firings required for break-even in 10 years at 12 firings per year (23.7 + 10 × (operating costs)/(cost per firing)) = $34M / $290K<br>= 117 firings in 10 years |
| • Number of firings saved per year to maintain cost effectiveness ($1M / $290K = 3.45 firings per year) |

A third alternative method of calculating the cost effectiveness of this type of facility is to record the number of errors found during HIL testing that would have caused a firing failure. Live firings are an expensive way of finding errors. We do not have the data required to conduct this type of analysis. However, we can approach it using the F/A-18 WSSF data, discussed in the next section.

### B.1.2 F/A-18 Weapons Software Support Facility (WSSF)

The F/A-18 Weapons Software Support Facility (WSSF) at China Lake, CA, is used for integration, checkout, and verification and validation (V&V) of avionics software with actual avionics hardware operating as a total aircraft system. The WSSF is actually several facilities containing avionics hardware, simulations of flight dynamics, weapons simulations, and operator consoles. Table B-4 shows the WSSF cost factors used in the following example calculations.

**Table B-4. F/A-18 WSSF Cost Factors**

| | |
|---|---|
| BRAC Replacement Cost | $54 M |
| Yearly Operating Cost | $6 to 8 M |
| Number of Test Hours per Year | over 6,000 |
| Lab Costs per Hour (F/A-18) | $930 |
| Lab Costs per Hour (other aircraft) | $1550 |
| Ground Costs per Hour | $100 |
| Flight Costs per Hour | $2,800 |

The WSSF is also used by weapons programs for integration and checkout of their aircraft interfaces. In addition, it has been used to supply simulated aircraft for other tests. The cost savings being computed (Tables B-6 and 6) are just the savings for the F/A-18, not for all programs using the facility. It is important to note that the cost per flight used here is the actual figure charged to the project. The true fully amortized cost of keeping an F/A-18 in the air and flight ready is probably much higher. The topic here is methodology.

### Table B-5. F/A-18 WSSF A/B Software Upgrade

| Cost Component | Hours Expended | % Errors Found |
|---|---|---|
| Lab Hours | 1,084 | 73% |
| Ground Hours | 81 | 2% |
| Flight Hours | 195 | 11% |
| Other Methods[4] | ? | 14% |

### Table B-6. F/A-18 WSSF C/D Software Upgrade

| Cost Component | Hours Expended | % Errors Found |
|---|---|---|
| Lab Hours | 4,957 | 61% |
| Ground Hours | 440 | 4% |
| Flight Hours | 966 | 13% |
| Other Methods | ? | 22% |

The more errors that can be found in the early stages of development using WSSF, the cheaper the overall program will be without even considering safety issues. Ground tests are relatively cheap, but they can only be used for simple power checks. They are included here so that total errors add up to 100%. Table B-7 depicts example savings calculations.

### Table B-7. WSSF Example Savings Calculations

| Cost Savings Method (assumes use of flight hours for all lab debug) | | |
|---|---|---|
| Cost of flight hours (A/B) | 1,084 hrs × $2,800/hr | $3M |
| Cost of flight hours (C/D) | 4,957 hrs × $2,800/hr | + $14M |
| Total cost of flight hours | | $17M |
| Annual operating costs | | - 7M |
| Savings per year | | $10M |
| However, there are not enough local planes to fly 6,000 hours in one year. | | |

The break-even viewpoint, based on replacement and operating costs (Table B-8), yields a more reasonable number of flight hours, but even that is difficult for one test facility to bear. If each lab hour equated to a flight hour, we would need more than one facility testing the software, or we would need more F/A-18s dedicated to software integration and test. The WSSF actually has several labs which may be used in parallel.

[4] Includes code reviews and other paper-based checks.

**Table B-8. WSSF Example Break-Even Calculations**

| Time to Break-Even Method | |
|---|---|
| Replacement costs | $54M |
| Maintenance costs ($7M per year) | + $70M |
| Total costs | $124M |
| Cost per flight | $2,880 |
| Have to save 4,400 flights per year for 10 years ($124M/$2,880 = 4,428) | |

The real value added of the WSSF is that an aircraft as complex as the F/A-18 is not possible without this type of test facility. We could not fly enough to test it. There is a danger in just looking at cost savings as the measure of whether or not we invest in M&S. As we demand more from our warfighting systems—safer, more accurate, more environmentally friendly, more stealthy, longer range, etc.—we will have to demand more from our test and training systems.

### B.1.3 Kernel Blitz

Kernel Blitz was a fleet training exercise (FLEETEX) that included live ships, submarines, aircraft, and land troops. The simulation portion augmented the fleet with additional synthetic ships, submarines, aircraft, and weapons. The simulation center used several existing computer facilities (including both coasts) and existing communications capability to link to platforms. A purpose of the exercise was to show that the use of simulated assets could add realism and complexity to training exercises. The costs of these simulated assets are depicted in Table B-9.

**Table B-9. Kernel Blitz**

| | |
|---|---|
| **Cost of Assets Simulated** | |
| Ships and submarines (23 platforms × 2 days × $100K/day) | $4.6M |
| Aircraft (27 platforms × 4 hrs × $3K/hr) | +$0.3M |
| Weapons (23 weapons × $500K/weapon) | +$11.5M |
| **Costs** | |
| BFTT Enhancements | –$350K |
| **Total Savings** | $16M |

The Battle Force Tactical Trainer (BFTT) existed prior to Kernel Blitz but was enhanced for this exercise. During Kernel Blitz, 33 real ships and submarines were used. The simulated assets significantly increased that number. The commanders at sea quickly forgot who was real and who was not. The fleet commands will have to answer the question of whether they would ever put 55 ships and subs into a training exercise.

The $500K per weapon may seem high to some, but it is the value used by the BFTT office (the AMRAAM is running about $250K per copy).[5] Regardless of what we think about the full cost of all the simulated assets, the $350K modification costs are impressively low (they represent only those costs charged to Kernel Blitz via BFTT). If we counted only the use of two ships for two days ($400K), the Navy would recoup its investment.

A study by the Center for Naval Analyses (CNA) [Neuberger and Shea 1995] states that "At this point, simulation should be viewed as enriching training and increasing readiness rather than reducing costs." The CNA analysis also specified much greater costs. However, the purpose of this discussion is not to determine the cost effectiveness of Kernel Blitz, but to demonstrate possible analytic methods.

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[5] There may likely be different cost factors included in the $500K and $250K values.

## B.2 IS COST SAVINGS THE BEST MEASURE OF M&S EFFECTIVENESS?

There are four basic categories of effectiveness measures obtained from applying modeling and simulation—*doing it better, doing it faster, doing it cheaper, doing it at all.* By "doing it better," we mean that the quality of the product or the quality of the processes employed is improved through the application of M&S. This is sometimes hard to measure in terms of dollar savings. *What value do we put on safer processes? We know how to determine the cost of a disaster, but what about the cost of near misses?* Is there a savings from reducing the number of near misses? We can usually obtain dollar savings for more accurate testing, earlier discovery of problems, and repeatability of testing, although there will be some subjectivity in the figures.

Simulations make it possible to conduct training events or test events that would not be possible or affordable if conducted live. *Is it reasonable to compare the cost of a simulated event to the cost of a live event that never would have occurred?* Better would be to compare the costs and effects of two realistic but different live and simulated events. However, we often lack the appropriate effectiveness measures.

Sometimes, it just would not be possible to conduct a specific test, or train for a specific situation, without simulation. For instance, in testing seekers, there are neither enough test points nor space to hook up test equipment to obtain all the information needed about the behavior of the hardware. By using a simulation, we have access to all parameters. For aircraft, we want them to be able to withstand a certain amount of G-loading, but *to actually test that would mean risking the loss of an aircraft at the edge of its envelope*—so we simulate the effects of Gs through application of M&S.

When classifying the effectiveness of M&S, much depends upon its application. Is it a wargame or an engineering simulation? Identifying effectiveness measures for the different M&S applications would make it easier for users to keep track of the effects of M&S. For instance, wargames may save money by identifying shortfalls of existing weapons by pointing out tactical solutions vice acquisition solutions, or by identifying a set of equally effective solutions from which the least expensive can be chosen. Engineering simulations save money by enabling faster design. *But what is the value added by increasing the number of alternatives considered through simulation?*

## B.3 CANDIDATE MEASURES OF EFFECTIVENESS

Table B-10 lists candidate measures of effectiveness (MOEs) and how they may be derived or calculated. The application space is mission planning.

**Table B-10. Mission Planning**

| | Candidate MOE | Determination of MOE |
|---|---|---|
| **Do It Faster** | Actual time savings of commanders doing the strategy, per mission | Review mission planning times |
| | Value added of "quick reaction" capability: shorten war, avoid casualties | Wargame with and without M&S capability |
| **Do It Better** | Value added of additional (on-line) information to mission planners | Review costs of mistakes, wargaming |
| | Value added of considering additional strategies | Wargame with and without M&S capability |
| | Value added of considering multiple enemy reactions to strategy | Review costs of unexpected reactions |
| **Do It Cheaper** | Cost savings of using new methods | Review cost of current equipment and compare to projected costs |
| **Do It At All** | Value added of retargeting mission en route | Number of "wasted" missions |
| | Value added of more detailed planning | Operator assessment of mistakes caused by ambiguity |
| | Value added of automatic recording or of review of strategies, scenarios and lessons learned | Evaluate mission planning training methods |

Table B-11 lists candidate MOEs for M&S tools that support analysis in support of Research, Development, Test and Evaluation (RDT&E). Examples of this type of analysis includes cost estimation, technical effectiveness evaluation, and cost and operational effectiveness analysis (COEA).

**Table B-11. RDT&E, Analysis**

| | Candidate MOE | Determination of MOE |
|---|---|---|
| **Do It Faster** | Better adherence to schedule<br><br>Use of virtual prototyping | Review daily program expenditures<br><br>Look at turn-around time for physical models |
| **Do It Better** | Value of adding more detailed analysis<br><br>Value added of considering more alternatives<br><br>Value added of making better decisions | Review number of design, software, planning changes<br><br>Review pre-planned product improvement, cost reduction, packaging efforts<br><br>Estimate of unknown unknowns, number of backup plans used for risk mitigation |
| **Do It Cheaper** | Cost savings of using new methods | Review cost of current equipment purchase, use, and maintenance and compare to projected costs |
| **Do It At All** | Value added of "executable requirements"<br><br>Value added of operators of virtual prototyping | Costs of erroneous requirements: suits, redesigns, ambiguities<br><br>Costs of failing operational evaluation |

Table B-12 lists candidate MOEs for M&S tools employed in the design phase of RDT&E. Examples include trade-off studies, engineering simulations, parametric optimization, maintenance planning, logistics planning, and production planning.

**Table B-12. RDT&E, Design Phase**

| | Candidate MOE | Determination of MOE |
|---|---|---|
| **Do It Faster** | Reduction of design iterations<br><br>Automatic design documentation | Compare to similar efforts<br><br>Compare to manual methods |
| **Do It Better** | Incorporation of maintenance, logistics, and production considerations | Estimates of reduced life cycle costs from what simulations pointed out |
| **Do It Cheaper**<br>**Do It At All** | Use of virtual prototyping<br><br>Evaluation of designs under more situations | Cost of physical models<br><br>Estimated costs of design failure under those situations |

Table B-13 offers seven MOEs for M&S tools used in test and evaluation.

**Table B-13. Test and Evaluation**

| | Candidate MOE | Determination of MOE |
|---|---|---|
| **Do It Faster** | Better adherence to schedule | Daily cost of ranges, program slips |
| | Better use of flight test time | Percent of test time wasted |
| **Do It Better** | Value added of "monte carlo-ing" test conditions | Percent of operational requirements not physically tested but inferred from testing |
| | Value added of rehearsing test | Percent of tests wasted |
| | Earlier identification of problems | Look at cost and spending curves for phase of project, look at cost of engineering change proposals by phase |
| **Do It Cheaper** | Use of virtual prototyping | Cost of physical models |
| **Do It At All** | Evaluation of designs under more situations | Estimated costs of design failure under those situations |

Table B-14 lists seven candidate MOEs for M&S application to training and how those MOEs might be determined.

**Table B-14. Training**

| | Candidate MOE | Determination of MOE |
|---|---|---|
| **Do It Faster** | Cost savings for fewer training days | Review average number of days for specific training |
| | Value added of training en route | Percent delay in deployment due to training |
| **Do It Better** | Value added of exposing trainees to more situations | Review of operator errors |
| | Total assessment of trainee progress | Evaluation of individualized training to graduate some individuals early |
| **Do It Cheaper** | Cost savings of using new methods | Review cost of current methods and equipment |
| **Do It At All** | Individual remedial training | Review number of "flunked" trainees |
| | Virtual reality training in hazardous situations | Review casualties, accidents due to operator error |

And finally, Table B-15 lists candidate MOEs for M&S tools in support of military operations.

**Table B-15. Support to Military Operations**

| | Candidate MOE | Determination of MOE |
|---|---|---|
| **Do It Faster** | Logistics routing | Time saved with better method |
| **Do It Better** | Weapons mix studies, both platform and individual | Enhancement of capabilities from tailored mixes |
| **Do It Cheaper** | Reduction of personnel required to do analysis | Amount of analysis based upon simulation |
| **Do It At All** | Decision aids | Benefits of faster, better decisions |

## B.4 IDENTIFICATION OF EXPENDITURES

The previous sections identified several MOEs for M&S. This section takes a closer look at the costs. Ideally, cost estimation would be the responsibility of each program manager when determining whether to pursue M&S versus other options. Too often we examine only the costs of building the simulation (or enhancing an existing one) and forget about the cost of V&V, training, operation, and maintenance.

*An additional shortcoming in assessing the cost effectiveness of M&S is that the cost of failure is rarely captured. With the large up-front costs associated with some M&S tools, a considerable amount of money can be spent before determining that the tool simply will not work. Unfortunately, these lessons learned rarely get publicized, so we "learn" the same lessons repeatedly.*

The costs of an M&S tool are less dependent upon its application domain and more dependent upon its physical implementation. If a simulation is entirely software, its costs can be identified in the same fashion as any other software system. The same is true of hardware-in-the-loop and live simulations.

The greatest difficulty in acquiring data is getting the right data and understanding its meaning and limits. It is imperative that the M&S community decide what data it needs and provide guidelines to program managers on how to record that data. It does not have to be difficult if people know from the beginning what is needed.

needs and provide guidelines to program managers on how to record that data. It does not have to be difficult if people know from the beginning what is needed.

The second problem is making sure the data are used correctly. Good data used against the provider will not engender more good data. This is a political problem and hence more difficult to solve than the first.

Table B-16 summarizes the identification of expenditures.

**Table B-16. Identification of Expenditures**

| | Area of Cost Saving or Avoidance | Determination of MOE |
|---|---|---|
| **Build** | The simulation is a product, just like a weapon system | Treat like an acquisition program, important to do a feasibility study |
| | Costs of "productizing" M&S; making it usable by several people | May be applicable if using a legacy simulation |
| | Integration of simulation with other simulations or hardware | May have to pay to modify interface software or equipment |
| **Prove** | VV&A | Probably 50% of acquisition costs, simulations are software intensive |
| | Operator acceptance—do the users and customers believe the results? | Need operator involvement from start, increasing acquisition costs |
| | Validation testing | Actual hardware tests to validate the models may include live ordnance firings—number and type need to be determined during program planning |
| **Use** | Training of users | Recurring cost—users will change |
| | Training of facilitators—people who train the users and run the simulation | Recurring cost but at a slower pace than training of users |
| | Computer time | Lease or ownership costs |
| | Equipment storage, access to space | May be leased |
| | Scheduling time | Delay to program because simulation facility was not available exactly when needed |
| | Setup costs | Simulation may be scenario dependent or user tailored |
| | Duplication of equipment | Users may choose to purchase their own systems—they also need to duplicate facilitator costs and |

| | | |
|---|---|---|
| **Feed** | Population of databases | Dependent upon scenario, access to, and cost of data |
| | Equipment maintenance contracts | Recurring costs |
| | Configuration management | Recurring costs |
| | Depreciation of equipment | Sometimes applicable |
| | Lease of communications lines | Recurring costs |
| | Update of databases | Scenario dependent |
| | Software support activity | Make modifications, upgrade, fix |
| | Revalidation | Each time a change is made |
| | Maintenance of libraries | Baselines and distributing releases |
| | Point of contact for questions | Necessary if system at multiple sites |

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[Allen and Smith 1994]
G. Allen and R. D. Smith. "TACSIM: Intelligence Training for Tomorrow's Battlefield." *Military Intelligence* 20 (4) (October-December 1994): 23-27.

This article provides information on Tactical Simulation (TACSIM), an interactive computer-based simulation to support intelligence training. TACSIM originally was developed as the "Post Oak" simulator in 1979 and renamed to TACSIM in 1980. Its initial function exercised intelligence missions utilizing scripted scenario databases against enemy forces and generating reports in U.S. Message Text Format (USMTF). According to the article, TACSIM development continues and currently supports the Distributed Interactive Simulation (DIS) and Aggregate-Level Simulation Protocol (ALSP). This is a thorough article covering TACSIM from its origin in 1979 to the present. It contains detail on TACSIM's employment and lists collection assets, but remains understandable to those outside the intelligence community. When discussing scripting, sensor flexibility, and TACSIM analysis, the article focuses on the function and responsibilities of military intelligence. This contributor (TACSIM) to ALSP is an integral part in the overall success of the Confederation of Models currently incorporated in ALSP. Here is a pertinent article that portrays this simulation in an easily understood manner.

[Alluisi 1991]
E. A. Alluisi. "The Development of Technology for Collective Training: SIMNET, a Case History." *Human Factors* 33 (1991): 343-362.

SIMNET, an acronym for simulator networking, was initiated in 1983 as a project on large-scale simulator networking by the Defense Advanced Research Projects Agency. This paper summarized the technical history of SIMNET development and identifies lessons learned that could contribute to the success of future efforts to develop training technologies and systems, especially for collective training. It concludes with a discussion of the implications and challenges of SIMNET for the human factors and training technology communities.

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[Andrews et al. 1992]

D. H. Andrews, W. L. Wang, and H. H. Bell. "Training Technologies Applied to Team Training: Military Examples." In *Teams: Their Training and Performance*, R. W. Swezey and E. Salas, eds. Ablex, Norwood, NJ, 1992.

The authors provide an overview of the need for team training in the military and the use of simulators to deliver this training. Examples of training technologies employing simulators for team training are provided, citing Army, Navy, and Air Force applications. Future trends are noted.

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[Angier et al. 1993]

B. N. Angier, E. A. Alluisi, and S. A. Horowitz. *Simulators and Enhanced Training*. IDA Paper P-2672. Institute for Defense Analyses, Alexandria, VA, 1992.

This study focuses on the issue of whether increased use of individual and networked simulators and training devices holds the potential to maintain military manpower capability during a period of declining budgets and force levels. It reviews findings of several previous studies, highlighting key findings. The operating costs of flight simulators are about 10% of actual equipment per hour trained; if acquisition cost is taken into account, the yearly operating cost is about 33% of actual equipment. The majority of tasks trained on simulators (59%) have significant positive transfer to flight performance (transfer effectiveness ratios greater than 0.33). The authors suggest a cautious approach to increased use of simulation in lieu of flying hours, but felt that it would not be overly risky to transfer perhaps 5% of the flying hour budget to simulator acquisition and operation. Analysis of an effectiveness comparison between simulator networking (SIMNET) and home-station field training indicates that SIMNET is extremely effective in increasing performance for SIMNET-trainable tasks relative to field training. Tradeoff analyses shows that investment in SIMNET-like facilities could be repaid by an 8 to 14% decrease in operating tempo (OPTEMPO).

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[Armed Forces Journal 1993]

"Training & Simulation: Battleground for Digitized Warriors." *Armed Forces Journal International* 132 (4) (November 1993): 40-41.

This article focuses on the missions of the Army's Simulation, Training, and Instrumentation Command (STRICOM), headquartered in Orlando, FL. STRICOM is

responsible for managing DOD technical efforts in Distributed Interactive Simulation, networking simulation components throughout the world, and developing and purchasing specialized training and simulation devices. It describes STRICOM's efforts in linking battle labs and battlefields, and concludes with a brief discussion of its progress in modeling equipment for allies. This short article, which provides the reader with a basic knowledge of STRICOM, educates those previously unaware of this command and highlights its importance to DoD's efforts to link training and testing resources throughout the services.

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[ARI 1995a]
Army Research Institute for the Behavioral and Social Sciences. "ARI Support of Tactical Engagement Simulation." *ARI Newsletter* 5 (1) (1995): 1-15.

This special issue describes ARI's key contributions to the development of tactical engagement simulation (TES). It begins with an historical overview of TES and MILES and their impact on the evolution of Combat Training Centers (CTCs). Other articles address lessons learned and the value of virtual and constructive simulation, including Distributed Interactive Simulation (DIS), for multi-service and Reserve Component (RC) tasks. One article, for example, presents data supporting the value of DIS for multi-Service Close Air Support training. Another article presents data showing the value of JANUS and SIMNET for training RC units.

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[ARI 1995b]
Army Research Institute for the Behavioral and Social Sciences. "Simulator Training Research Advanced Testbed for Aviation (STRATA)." *ARI Newsletter* 5 (2) (1995): 7-12.

The ARI STRATA facility at Ft. Rucker, AL, provides a powerful tool for collecting helicopter pilot training and cost-effectiveness data. This article summarizes experiments conducted since the arrival of STRATA at Ft. Rucker in 1992. One series of experiments validated STRATA for simulating AH-64H helicopter tasks. A second series tested alternative training in a traditional lockstep manner. Experimentally trained crews had higher gunnery scores, sustained less battle damage, and engaged more targets than the control crews.

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[Army Science Board 1989]
Army Science Board. *Close Combat (Heavy) Training Strategy for the 1990s.* U.S. Department of Defense, Washington, DC, March 1989.

The Army Science Board conducted a study of the training strategy for heavy forces, with a focus on the role that simulation might have in future Army training. The board expressed the opinion that it would be possible to reduce OPTEMPO (operating tempo) and training ammunition by 15 to 20% while maintaining the same or a better level of unit performance, provided that (1) compensating funds would be provided to enhance and operate simulators, (2) simulators could be tailored to the special needs of units, and (3) simulators would be used effectively. The reduction assumed a base-level tank main gun annual ammunition allocation of 100 rounds (active) and 48 rounds (National Guard), 800 miles per vehicle, and 15.8 flight hours per pilot per month.

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[Automotive Industry Action Group 1994]
Automotive Industry Action Group (AIAG). *Solid Modeling White Paper.* AIAG, Southfield, MI, June 1994.

This white paper is the result of a request from the AIAG Original Equipment Manufacturer Computer-Assisted Design/Computer-Assisted Manufacturing (OEM CAD/CAM) Task Force that a work group composed of members from Chrysler, Ford, and General Motors be formed to write a white paper on solid modeling. Representatives from each of the three automobile manufacturers provided information concerning their past and present experience with solid modeling, as well as indications of their strategies for the future.

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[Automotive Engineering 1994a]
"Driving Simulation at Ford." *Automotive Engineering* (September 1994): 37-40.

This article reviews Ford's experience in using simulation in studying driver performance in the same controlled manner as simulation is used in studying mechanical vehicle components. The information was supplied by Jeffry A. Greenberg and Thomas J. Park of the Ford Motor Co. Research Laboratory.

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[Automotive Engineering 1994b]
"Driving." *Automotive Engineering* (September 1994): 14-19.

The role of driving simulation in the vehicle design process at General Motors (GM) is reviewed in this article. The article suggests that the GM driving simulator is a viable tool for studies performed in the on-center region of vehicle performance. Additional conclusions and recommendations for using driving simulators are presented. Information for this article was supplied by Gary P. Bertollini, Charles M. Johnson, James W. Kuiper, James C. Kukula, Malgorzata A. Robzveka, and William E. Thomas, all of GM.

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[Bailey 1995]
M. Bailey. *Value of Modeling and Simulation.* Memorandum to the M&S Benefits Task Force. Naval Air Warfare Center, Weapons Division (NAWCWD), China Lake, CA, May 1995.

Bailey writes that the "beef" of M&S "resides in the intelligent and informed application of modeling and simulation to reduce risk, avoid safety/environmental/security issues, and increase the quality of training and equipment." She concludes that M&S is a tool of substantial assistance to the military when properly applied.

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[Bailey and Hodak 1994]
S. S. Bailey and G. W. Hodak. *Live Fire Versus Simulation: A Review of the Literature.* NAWCTSD-SR-94-002. Naval Air Warfare Center, Training Systems Division, Orlando, FL, 1994.

The authors reviewed several studies relating to the use of simulation in lieu of live fire for the purpose of reducing the cost of training Marine Corps personnel. Ammunition costs for training Marines range from $1,762 (MOS 0311, rifleman) to $19,145 (MOS 0352, TOW II gunner). Many of the empirical studies have demonstrated that performance with simulation is at least equal to live fire training, but that cost is lower. The Multipurpose Arcade Combat Simulator (MACS) is used to augment training on the M16 rifle and small weapons. Effectiveness studies did not find a statistically significant difference between live fire and simulation, but soldiers with MACS training expended less rounds during live-fire qualifications and fewer soldiers failed to qualify when compared to those trained using traditional methods. The Weaponeer is a part task trainer for training on a variety of weapons, including M16, SAW, M60, AT-4, and M203 grenade launcher. Weaponeer can be used to predict and record fire performance, but no data are available on its training effectiveness. The Squad Engagement Training System (SETS) is used to provide marksmanship and tactical training for up to and including squad level. Several studies have shown positive transfer from SETS to live fire. The Indoor Simulated Marksmanship Trainer (ISMT) is used to train on several small arms and has been demonstrated to benefit live-fire performance. The Precision Gunnery Training System (PGTS) is an inexpensive trainer for the TOW and Dragon missiles, whose rounds are prohibitively expensive ($11,500 and $19,145, respectively, per round) to fire in training exercises. PGTS has been demonstrated to be cost effective, and also permits training that would otherwise cost several hundred million dollars per year if actual missiles were used.

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[Baker et al. 1994]
E. R. Baker, L. Cooper, B. A. Carson, and A. E. Stevens. "Software Acquisition Management Maturity Model (SAM3)." *Program Manager* 23 (4) (July-August 1994): 43-48.

This article describes SAM3 and its underlying concepts. SAM3 is a hierarchical structure of Key Process Areas, Key Practices, and Key Indicators. It is organized into five levels of maturity: Initial, Repeatable, Defined, Managed, and Optimizing. The acquisition management maturity model is the basis for assessments of the acquisition management capabilities of the organization. This article provides a clear explanation for a complex model. Graphics add to the presentation and greatly assist the reader in understanding the model.

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[Bell and Crane 1992]
H. H. Bell and P. M. Crane. *Training Utility of Multiship Air Combat Simulation*. USAF Armstrong Laboratory, Mesa, AZ, 1992.

The authors describe evaluations with developmental distributed interactive simulation (DIS) systems designed to support multiship air combat training in a combat engagement simulation environment. In the first evaluation, the simulator realistically represents the threat environment (e.g., two F-15 cockpits, visual world, enemy surface-to-air and electronic jamming, enemy aircraft, pilots and air weapons controllers). Responses of participating pilots and air weapons controllers indicate that they believed that some mission areas were better trained in the simulator than in unit training: multibogey, reaction to SAM, dissimilar air combat tactics, employment of electronic countermeasures

(ECM), all-aspect defense, escort tactics, all-weather employment, communications jamming, low-altitude tactics, threat warning assessment, and work with air weapons controller. Mission areas where simulator training was rated inferior to unit training were visual lookout, tactical formation, visual identification, and mutual support.

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[Berg et al. 1993a]
R. M. Berg, A. M. Adedeji, and G. W. Steadman. *Simulation Offset to Live Fire Training Phase 2 Results: Application of the At Least Equal Effectiveness Methodology to Simulator Use in Marine Corps Infantry Training Programs.* CRM-93-112. Center for Naval Analyses, Alexandria, VA, 1993.

This study addresses this question: "To what extent does it make sense—from both training effectiveness and cost perspectives—for the Marine Corps to use simulators in performing infantry training tasks that are now done predominantly with live-fire?" The study concludes that third-generation simulators such as Indoor Simulated Marksmanship Trainer (ISMT) can be used cost effectively in USMC live-fire training programs, that procuring them would be a very good investment, that they would increase the overall quality and effectiveness of training, and significantly reduce the total annual cost of training. The authors recommend that the USMC "proceed expeditiously to implement this type of system into its infantry training programs."

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[Berg et al. 1993b]
R. M. Berg, A. M. Adedeji, and C. Trenholm. *Simulation Offset to Live Fire Training Study: Assessment of Marine Corps Live Fire Training Support.* CIM-238. Center for Naval Analyses, Alexandria, VA, 1993.

The USMC has traditionally emphasized live-fire training and placed low priority on acquiring simulators. Anticipated reductions in training resources led to this study of the potential use of simulators in lieu of live training. The study examines simulators currently used in the USMC and Army and the potential for expanded use in the USMC. The training of infantry marksmanship is estimated to be the single most expensive training program in the USMC. M16A2 rifle qualification requires each Marine to fire 250 rounds on the rifle range. The biggest cost driver in marksmanship training is the cost of training ammunition. Additional significant costs are involved in operating and maintaining ranges. Simulators, such as the Multipurpose Arcade Combat Simulator (MACS), have the potential to significantly reduce these costs in the USMC.

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[Bessemer 1991]
D. W. Bessemer. *Transfer of SIMNET Training in the Armor Officer Basic Course*. ARI TR 920. USA Research Institute Field Unit—Ft. Knox, Ft. Knox, KY, 1991.

Bessemer describes a quasi-experimental assessment of transfer of tactical training from SIMNET to field training. Baseline classes without simulator training were compared in an interrupted time series design to classes with simulator training. Transfer was found using indicators of (1) the amount and type of field training, (2) platoon-level officer leadership performance, and (3) overall tactical leadership qualities just prior to graduation. Benefits of simulator training increased in successive classes as instructors learned to train with simulators more effectively.

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[Boldovici and Bessemer 1994]
J. A. Boldovici and D. W. Bessemer. *Training Research with SIMNET: Lessons Learned from Simulation Networking*. ARI Technical Report 1006. USA Research Institute Field Unit—Ft. Knox, Ft. Knox, KY, 1994.

The authors provide a critique of methods commonly used in field experiments to evaluate training systems. In a review of several reports of training effectiveness research as applicable to evaluation of the Close Combat Tactical Trainer (CCTT), the authors conclude that one-shot empirical evaluations of the kind needed to meet acquisition, test, and evaluation regulations (e.g., AR 70-1, TRADOC regulations 71-9 and 350-4) are costly and often so flawed by compromises in research design that they are unlikely to meet evaluation objectives. Common problems are insufficient statistical power, inadequate sampling, inappropriate analyses, inadequate controls, and lack of control data. The authors recommend that evaluators consider alternatives to empirical evaluations such as in-device learning experiments, quasi-experimental designs, and correlational methods.

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[Boldovici et al. 1985]
J. A. Boldovici, D. W. Bessemer, and D. F. Haggard. *Review of the M1 Unit-Conduct of Fire Trainer (*UCOFT*) Validation and Verification Test Report.* ARI Research Note 85-56. USA Research Institute Field Unit—Ft. Knox, Ft. Knox, KY, 1985.

This review was performed at the request of the then-Under Secretary of the Army, James Ambrose. It examines the somewhat mixed evidence contained in the UCOFT Validation and Verification (V/V) test report, and concludes that the UCOFT provided improvements in gunner proficiency on the UCOFT under a number of different conditions, although the V/V did not demonstrate transfer to operational equipment. Substantial gains were found in percents of targets acquired, engaged, hit, and killed for groups undergoing sustainment and transition training. Gains were attributed to improvements in acquisition time, engagement time, and first-round hits, which in turn allowed time to scan, acquire, and engage available second and third targets.

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[Brown 1992]
F. J. Brown. *Battle Command Staff Training*. Institute for Defense Analyses, Alexandria, VA, December 1992.

The objective of this paper is to design and develop a new distributed simulation-based intensified training readiness strategy for the Reserve Component. The author introduces "...an innovative prototype for training battle staff synchronization using advanced distributed simulation." This innovative prototype is called Battle Command Staff Training (BCST). Its focus, on the battalion and brigade levels, shows how this new training strategy will positively affect the Reserve Component unit. In their day (late 1970s, early 1980s), these simulation training devices were novel. Today, the state of the art is generations beyond the battalion and brigade simulations presented here. This brief paper, with appendices and supplementary tables, addresses the value of distance learning. It asserts that distance learning is the wave of the future. The author proposes BCST as a new model for training. His use of the term "model" refers to structure, rather than a computer program. The simulation-based strategy to which he refers is simply the leveraging of existing battalion and brigade simulations that are used extensively by the Active Component.

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[Brown et al. 1988]
R. E. Brown, R. G. Pishel, and L. D. Southard. *Simulation Networking*. TRAC-WSMR-TEA-8-99. USA TRADOC Analysis Command, White Sands Missile Range, NM, 1988.

SIMNET effectiveness as a platoon-level tactical training device is evaluated by comparing before vs. after training performance results for a SIMNET-trained group and a field-trained control group. Both training groups consist of four M1 tank platoons. Principal results are that SIMNET training increased field exercise platoon performance, command and control, and leadership, and adequately portrayed vehicle and battlefield sounds. SIMNET is reported to be ineffective for training tasks related to obstacles,

dismounting troops, air attack, and use of smoke. The visual display is inadequate for viewing objects beyond 1,000 meters and for identifying hull/turret-down defiled positions. The simulated M1 tank speed is unrealistic. SIMNET also improved performance of command and control, platoon movement, leadership, and fire distribution during the company team Army Training and Evaluation Program (ARTEP).

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[Bryant et al. 1992]
J. A. Bryant, N. L. Lewis, M. Stapp, A. A. Zamarripa, J. Cox, J. Wilhelm, and M. Walker. *JANUS(A) Brigade/Battalion Simulation Cost and Training Effectiveness Analysis.* TRAC-WSMR-CTEA-92-006. USA TRADOC Analysis Command, White Sands Missile Range, NM, 1992.

This Cost and Training Effectiveness Analysis assesses the command and control portion of the Simulator/Simulation-Based Training Program Analysis (SIM2) and the Battalion/Brigade Battle Simulation (BBS), based on analyses and opinion data gathered from subject matter experts and supported by a literature review to provide historical data on the simulations. The literature review indicates that JANUS(A) is effective in training company-level officers and platoon leaders on current tactics and doctrine and that BBS is effective at the brigade/battalion level. Study results indicate that a large percentage of mission training plan tasks can be trained in the Close Combat Tactical Trainer (CCTT), JANUS(A), BBS, and CCTT have somewhat overlapping, but also individually unique training capabilities. Based on a 15-year life expectancy, the hourly cost of using JANUS(A) was estimated to be $163.

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[Burnside 1990]
B. L. Burnside. *Assessing the Capabilities of Training Simulations: A Method and Simulation Network (SIMNET) Application.* ARI Research Report 1565. USA Research Institute for the Behavioral and Social Sciences, Alexandria, VA, 1990.

Burnside describes a method developed for assessing Army Training and Evaluation Program (ARTEP) Mission Training Plan (MTP) standards that can be met and subtasks and tasks that can be performed when conducting training with TADSS. The method is applied to assess the performance capabilities of SIMNET. Using the criterion that tasks must be at least partially performable to be trainable in SIMNET, the study finds that 35% of ARTEP MTP tasks can be trained with SIMNET. The platoon echelon has the highest percentage of trainable tasks (41%) and of tasks not supported by the simulation (46%).

The author concludes that the method provides an efficient means to assess the capabilities and requirements of TADSS.

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[Case 1991]
F. T. Case. *Analysis of Air Operations During Desert Shield/Desert Storm*. AFSAA Report No. 28467; DTIC AD-B161 849. Air Force Studies and Analysis Agency, Department of the Air Force, Washington, DC, November 1991.

*No abstract available.*

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[Center for Naval Analyses 1995]
Center for Naval Analyses. *Developing a Navy Strategy for Modeling and Simulation: Final Report.* Center for Naval Analyses, Alexandria, VA, March 1995.

This report develops a Navy strategy for modeling and simulation through a series of 20 recommendations regarding Navy modeling and simulation. These recommendations, which are first presented in numerical order with a brief explanation, are then grouped under the areas of the Navy modeling community, distributed simulation, acquisition support, test and evaluation, training, and verification, validation and accreditation. The second grouping includes conclusions, recommendations, and justifications for each of the 20 points. The report presents some valid recommendations in a number of key areas in the modeling and simulation community. Although the report purports a plan of action to achieve each of the recommendations expressed, it frequently provides insufficient detail to validate the recommendation. The summary of key study conclusions discusses the need for centralized coordination of modeling development, and the conclusion that modeling and simulation can contribute meaningfully to the quality of Navy acquisition, test and evaluation, and training. The most meaningful topic for training and education is contained in Appendix E, Training Applications.

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[Crane and Berger 1993]
P. M. Crane and S. C. Berger. *Multiplayer Simulator Based Training for Air Combat.* USAF Armstrong Laboratory, Williams AFB, AZ, 1993.

The authors describe Training Requirements Utility Evaluation (TRUE), a series of simulated air combat exercises conducted in Multiship Research and Development Program (MULTIRAD), a SIMNET-compatible an air combat simulator. TRUE was conducted to identify mission tasks and skills that can be effectively trained using

multiplayer simulation. Pilots received training on MULTIRAD and then rated their interest in receiving additional training on each of 30 tasks. The five tasks with the lowest rated interest are primarily visual tasks. Tasks with the highest rated interest can usually be practiced only in large exercises or cannot be practiced except in simulation. It was concluded that multiplayer simulator-based training is a valuable training medium for increasing wartime readiness, especially for less experienced pilots.

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[Davis 1991]

P. Davis. Letter included in the Congressional Record Volume, "The CFE Treaty," from hearing before the Subcommittee on European Affairs Committee of Foreign Relations, U.S. Senate, March 20, 1991; July 11, 16, 17, and 25, 1991, pp. 327 and ff.

In a response to a Task Force request for information, Davis recommends the above citation as summarizing his perception of RAND work with simulation and the RAND Strategy Assessment System (RSAS) in affecting the CFE (Conventional Forces in Europe) negotiations. Additionally, he points out that the following could be claimed: "(1) Analysis based on simulation-based analysis conflicting with conventional wisdom strongly influenced NATO's insistence on highly asymmetric reductions toward equal ceilings; (2) analysis for the Office of the Secretary of Defense (OSD) clarified the circumstances under which deep reductions would and would not be militarily destabilizing, even with nominal ceilings; and (3) analysis for OSD, supported by simulation-based work, helped clarify and orient the US sense of objectives for confidence and security-building measures." Davis also recommends a paper by Jim Thompson and Nanette Gantz that had a major effect in determining NATO's position in the CFE negotiations. Davis points out that Thompson and Gantz's work, circa 1988, relied on simulation results from RSAS.

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[Defense Science Board 1988]

Defense Science Board. *Report of the Defense Science Board Task Force on Computer Applications to Training and Wargaming.* Office of the Under Secretary of Defense for Acquisition, Washington, DC, 1988.

This Defense Science Board (DSB), an advisory committee of senior military analysts chaired by Dr. Anita Jones, focused on the training of Joint operational commanders, their staffs, and the commanders and staffs who report to them. The report stated that computer-based, simulated scenarios offer the only practical and affordable means to

improve the training of Joint operational commanders, their staffs, and the commanders and staffs who report to them. Such decision makers need the opportunity to exercise their decision skills, to test war plans, and to train to work as a closely coordinated force. Increasingly, Joint training cannot be conducted in the anticipated theater of operations. There are political objections to disruption of civil activity. The cost of an actual exercise at this level is great. Battle simulation offers the only opportunity to practice the use of certain weapon systems, sensors, tactics, and techniques against a skilled adversary. The report recommended that the Chairman, Joint Chiefs of Staff (CJCS) make Joint simulations interoperable; promote their usage; and establish requirements for future capabilities, a prototype program, and undertake a major joint training initiative.

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[Defense Science Board 1993]
Defense Science Board. *Report of the Defense Science Board Task Force on Simulation, Readiness and Prototyping.* Office of the Under Secretary of Defense for Acquisition, Washington, DC, 1993.

This Defense Science Board, an advisory committee of senior military analysts co-chaired by Dr. Joseph Braddock and General Maxwell Thurman, USA (Ret.), focused on the effect of Advanced Distributed Simulation (ADS) technology on Service and Joint readiness. The task force declared the belief that ADS technology can greatly improve training and readiness, will help expedite prototyping, and can transform the acquisition process. The belief was based on a judgment concerning confidence. The task force found that the warfighting community has embraced ADS and is extending its utility: warfighters are applying distributed and multiple simulations methods to improve planning, training, and mission rehearsal. They have developed the confidence to use the technology to prepare for war. In contrast, the requirements and development community is using less powerful simulation techniques and the acquisition process is being handicapped.

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[Defense Science Board 1994]
Defense Science Board. *Report of the Defense Science Board Task Force on Readiness.* Office of the Under Secretary of Defense for Acquisition and Technology, Washington, DC, 1994.

This Defense Science Board, an advisory committee of senior military analysts chaired by General Edward Meyer, USA (Ret.), reviewed the state of readiness of the Armed Forces.

The report made the following remarks about the relationship of M&S to readiness. "Today, M&S offers great potential as an affordable and effective means by which Joint forces can achieve and maintain expertise in operational and tactical tasks, such as employing operational firepower, conducting strategic deployment, employing forces, developing theater intelligence, conducting mission rehearsal, and operational movement and maneuver. In the future, technologies of the 'Information Age' offer the prospect of making M&S increasingly more useful in enhancing Joint force readiness. Both prudence and economy dictate that DoD capitalize on Advanced Distributed Simulation (ADS) technology to prepare for Joint and Combined warfare in an uncertain world. ADS can provide the wherewithal for Joint Task Forces, and in particular Joint tasks for staffs, to practice more often and build confidence. Simulations offer the potential for markedly improving Joint requirements definition and refinement; Joint doctrine development and acquisition; test and evaluation; planning and course-of-action assessments or rehearsals; and military education. Live exercises and training, particularly those conducted on instrumented ranges (e.g., National Training Center, 29 Palms, Fallon, Nellis, etc.), will continue to provide the critical component of unit training. In recent years, however, the Services have exploited M&S technology to enhance individual and unit readiness while reducing overall training costs."

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[Deitchman 1988]

S. J. Deitchman. *Preliminary Exploration of the Use of a Warfare Simulation Model to Examine the Military Value of Training*. IDA Paper P-2094. Institute for Defense Analyses, Alexandria, VA, 1988.

This paper is a preliminary examination of how to assess the military value of unit training in the same quantitative cost and effectiveness terms used to assess investments in other areas such as acquisition of new weapon systems or of more forces of various kinds. The military value of training in relation to the value of weapons or forces is difficult to quantify, and data that would shed light on it are sparse; a new approach is proposed here. The approach consists, first, of experimenting with a large-scale computer simulation of warfare to find how imputed effects of unit training on unit proficiency affect the outcome of a modeled NATO/Warsaw Pact conventional conflict. Second, the outputs of the model runs are reviewed for reasonableness, and are used to set up a series of questions to elicit military judgments and any available test. The final steps will be to estimate the costs of the levels and kinds of training that emerge, and then to use similar modeling techniques (or existing results) to compare investments in training and in force size or force

modernization to achieve equal effects on the outcome of the war. This paper describes the first experiments, the results of the initial model runs, and the next steps to be taken in the investigation, in terms of questions to be answered by military experts, data to be gathered if they are available, analyses to be performed subsequently, and kinds of training that emerge. Then, similar modeling techniques (or existing results) are used to compare investments in training and in force size or force modernization to achieve equal effects on the outcome of the war.

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[Deitchman 1990]
S. J. Deitchman. *Further Explorations in Estimating the Military Value of Training.* IDA Paper P-2317. Institute for Defense Analyses, Alexandria, VA, 1990.

This report describes the continuation of work started earlier to find ways of quantifying the military value of training. The earlier work used a large-scale simulation model of warfare to examine the potential effects of assumed force improvements imputed to training on the outcome of a postulated war in Europe. The work described in this report gathered some of the available data showing the effects of training on force effectiveness, and it estimated the cost of training, in the areas of platoon-size armored combat and bombing accuracy by tactical attack aircraft. These results were compared with the results of analyses describing the effects of equipment improvement in the same areas of unit combat. The report shows the size of the effects in each case, and it evaluates the relative contributions of training and hardware advances to improvement of force effectiveness and the relative costs of the two approaches. Conclusions are reached about preferred approaches to such evaluations, and desirable future elaborations of the research are outlined.

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[Deitchman 1993]
S. J. Deitchman. *Quantifying the Military Value of Training for System and Force Acquisition Decisions: An Appreciation of the State of the Art.* IDA Paper P-2881. Institute for Defense Analyses, Alexandria, VA, 1993.

Deitchman reviews the state of knowledge regarding the contribution of collective training in military units to success in battle. The review of the "sparse relevant literature" indicates that unit training under realistic conditions can increase key military capabilities of units from platoon to battalion size (and equivalents in the air forces) by factors of 2 on average. Hardware advances can increase military capability by like amounts if the

requisite unit training is also provided. Without the investment in unit training, the capability of a military unit should be discounted by about 50%.

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[Deluca 1993]
R. Deluca. "Simulator Builders Boost Art in Courting Diversion Seekers." *National Defense* 128 (November 1993): 19-21.

This article focuses on the expansion of traditional defense simulator technologies into the commercial entertainment field and the reasons behind this shift. It cites the finite market of defense simulation sales, the wide-open commercial market, reduced delivery costs, and rapid improvements in hardware and software that make this challenging shift attractive. The article continues by discussing futuristic landscapes, the proliferation of applications, as well as current commercial constraints and solutions to networking problems. The article approaches simulation from a slightly different angle than one would expect to find in *National Defense* magazine: its subject is commercial simulation. It describes the concerns of the commercial simulation industry and the shift toward involvement in the field of entertainment. This article is of interest to those involved in defense simulations and illustrates a direct relationship between defense and entertainment applications.

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[Department of the Air Force 1993]
Department of the Air Force. *Response to Air Force Simulation Questions.* Unpublished manuscript. USAF, Washington, DC, 1993.

*No abstract available.*

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[Department of the Air Force 1995]
Department of the Air Force. "Simulation and Cost Savings." *Issues in Air Force Simulation and Analysis* (February 1995).

The author proposes that simulation should be used early in the acquisition process in order to "save time, decrease life cycle cost, and decrease risk." The author further states that "the use of prototyping and simulation for the integration of the Multi-mission Advanced Tactical Terminal (MATT) saved between one and three years of acquisition time."

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[Department of the Army 1993]
Department of the Army. *Simulations and Their Relationship to OPTEMPO/Training Ammunition*. Unpublished memorandum. USA, Washington, DC, 1993.

Virtual simulation is being used to reduce OPTEMPO (operating tempo), typically by reducing flying hours and the amount of training ammunition. An example is flight simulators for Cobras, Chinooks, Blackhawks, and Apaches. Air crew training manuals permit two flying hours per month to be replaced by simulators. Cost avoidance for the active component due to flight simulators is $68M annually. Fielding of the Conduct of Fire Trainer (COFT) reduced the annual tank main gun ammunition allocation from 134 to 100 rounds. This resulted in an annual cost avoidance of approximately $29M. It was predicted that future fielding of the Tank Weapons Gunnery Simulation System (TWGSS) FY96-001 would further reduce annual ammunition allocations from 100 to 78, an additional cost avoidance of $21M per year.

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[Department of the Army Operational Evaluation Command 1993]
Department of the Army Operational Evaluation Command. *Study Report: Utility of Synthetic Environments in Support of Operational Test and Evaluation.* USA, Alexandria, VA, 1993.

This study reports on an experiment conducted by the Army to evaluate the improved capability of the M1A2 tank versus the M1A1 tank and to examine the utility of synthetic environments for support of Operational Test and Evaluation (OT&E). The results of the study support the evaluation of the utility of synthetic environments in support of OT&E, pointing out that the existing SIMNET-D/SE is "good enough" for developing maneuver tactics, techniques, procedures, and doctrine. However, there are many limitations within the SIMNET-D that restrict its value for evaluating system capabilities. The Operational Evaluation Command recommends a series of improvements and tasks in order to fully exploit the inherent value of using synthetic environments using SIMNET-D technology.

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[Department of the Navy 1993a]
Department of the Navy. *Data Request for Issue Paper: Simulation Support to Readiness.* Memorandum for the Director, Force Structure Analysis Division (OSD PA&E). Unpublished memorandum. USN, Washington, DC, 1993.

*No abstract available.*

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[Department of the Navy 1993b]
USN. *Pacific Fleet and Atlantic Fleet Tactical Training Manual (TTM).* CINCPAC FLTINST/CINCLANTFLTINST 3501.1. USN, Washington, DC, 1993.

This instruction, referred to as the Tactical Training Manual (TTM), is the single source for tactical training policy and requirements for Pacific Fleet and Atlantic Fleet ships, submarines, aircraft squadrons, and tactical staffs. TTM is to be used by all groups planning or conducting training to ensure consistent training practices throughout the fleets. The TTM consists of 6 chapters with over 30 appendices that address unit-specific training requirements. The most important chapters cover the Tactical Training Strategy, the Training Process, and Measurements and Certification. The Tactical Training Strategy chapter provides a road map to achieve maximum combat readiness and interoperability between the Atlantic and Pacific Fleets. It discusses training philosophy, training responsibilities, tactical training organization, and the tactical training cycle necessary to achieve that objective. The Training Process chapter contains training precepts and training program guidelines for operational staffs, warfare commanders, and individual units. It discusses shore and sea basic training, intermediate training, and advanced training flows. The chapter on Measurements and Certification discusses the training assessment and feedback cycle, including establishing training objectives, scenario development, performance criteria selection, data collection plan development, reconstruction and analysis, and performance assessment and feedback. The TTM was written for use by command and training personnel at all levels to ensure a consistent training program. The philosophy of the instruction is well presented for all users, but the most important information is provided in the appendices which provide specific training cycle information for each ship class and aircraft squadron type as well as operational staffs and warfare commanders. This information is required for every Commanding Officer and Immediate Superior in Command who want to adequately plan their unit's training cycle.

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[Department of the Navy 1994a]
Department of the Navy. *Surface Force Training Manual.* COMNAVSURFPACINST/ COMNAVSURFLANTINST 3502.2. USN, Washington, DC, 1994.

This manual provides a comprehensive training program that integrates a sequence of individual, team, and unit training evolution in all areas applicable to the Naval Surface Forces in the Atlantic and Pacific Fleets. It is the primary directive for planning,

scheduling, and executing all cyclic and repetitive training requirements within the Naval Surface Forces. There are two significant areas in this instruction that have an effect on modeling and simulation: Tactical Training Strategy training cycle and the Exercise Equivalency Program. Chapter 2 details each phase and step of the Tactical Training Strategy training cycle. This is the same training cycle specified in the Tactical Training Manual. Chapter 2 also describes which phases and steps can be accomplished as shore-based training. The other significant area is detailed in Appendix C, Exercise Equivalencies. This appendix provides a matrix of those exercises approved for readiness reporting under the type commander's Exercise Equivalency Program. The Exercise Equivalency Program includes *only* scenarios run on one's own ship's systems, whether generated from shore-based and mobile (van) scenario generators or embedded, on-board scenario generators. The following is a list of the shore-based approved scenario generators: TACDEW, ENWGS, CSTS, Mobile Combat Systems Trainer Device 20B4, Mobile Combat Systems Trainer Device 20B5, Radar Video Recorder (RAVIR), LAMPS I/III Mobile Team Trainer Unit (LMTTU), and AN/SQR-17/17A "Rooftop" Transmitter, Device 14E12 (RFTOP). This manual was written for use by command and training personnel at all levels to properly plan, schedule, conduct, and document training. It provides clear cut guidance on training requirements and acceptable training alternatives. This information is required for every Commanding Officer and Immediate Superior in Command who want to adequately plan their unit's training cycle.

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[Department of the Navy 1994b]
Department of the Navy. *Threat Training Manual.* CINCPACFLTINST/CINCLANT-FLTINST S3057.1A. USN, Washington, DC, 1994.

This instruction is a SECRET supplement to the Tactical Training Manual. The Threat Training Manual provides standardized tools with which trainers and operators can develop widely varying threat scenarios according to their needs. The Threat Training Manual is designed to shift the focus of Fleet Tactical Training from the defunct Soviet Union toward a broad understanding of the other multi-form threats that U.S. Naval Forces could confront. Complementary to the Tactical Training Manual, the Threat Training Manual provides a toolbox of potential threat capabilities and tactics that can be used to develop scenarios. These threat scenarios will then be used to support training objectives throughout the Interdeployment Training Cycle that prepares units for overseas deployment.

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[DMSO 1995]

Defense Modeling and Simulation Office. *Modeling and Simulation (M&S) Master Plan.* Office of the Under Secretary of Defense (Acquisition and Technology), Washington, DC, January 1995.

The M&S Master Plan implements policy outlined in DoD Directive 5000.59, "DoD Modeling and Simulation (M&S) Management." It establishes DoD-wide M&S objectives; provides a comprehensive framework for the programming and budgeting of M&S projects, programs, and activities; and assigns responsibilities for its implementation.

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[DSMC 1994]

Defense Systems Management College. *Systems Acquisition Manager's Guide for the Use of Models and Simulations.* DSMC, Ft. Belvoir, VA, September 1994.

This guidebook is the result of an 11-month Military Research Fellowship program sponsored by the defense systems acquisition community and funded by the Defense Modeling and Simulation Office. It provides the acquisition community information on DoD policy regarding modeling and simulation (M&S) capability and how M&S can be applied throughout the acquisition cycle. It also gives Project Managers an understanding of dual-use technologies, faster and lower manufacturing costs, and complements Operational Test and Evaluation (OT&E). This guidebook, developed as a reference for the Project Manager, describes M&S policies, types of M&S, applications, and key technical and management issues. The study is organized into a preface, eight chapters, and an epilogue, with appendices listing detailed DoD M&S sources. Chapter One introduces the study, explaining the purpose, methodology, and objectives. Chapter Two discusses today's applications, the systems acquisition process, and the requirements generation process. Chapter Three gives a detailed description of DoD M&S, organization, and policy. Chapter Four outlines the classification of M&S, including live, virtual, and constructive technologies. Chapter Five addresses the acquisition life cycle, and Chapter Six outlines the acquisitions issues in the M&S community. Chapter Seven addresses management issues, and Chapter Eight looks to the future of M&S. The study is an excellent and comprehensive work outlining DoD's M&S organization and policy. It identifies the key task for the future, which is defining and providing an infrastructure to combine individual M&S into a seamless live, virtual, and constructive world. The study addresses the need for standards for interface definition, communication, representation of environment, management, security, field instrumentation, and performance measurement.

While not an objective of this study, a more comprehensive look at user requirements generation and addressing the merger of combat, materiel, and training developments models might have been discussed in more detail. The cost of M&S is driving both the training and OT&E communities in this direction. The fidelity issue for training versus OT&E must be addressed. From a cost and proficiency standpoint, separate M&S for each community is unacceptable.

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[Eisley et al. 1990]
M. E. Eisley, J. D. Hagman, R. L. Ashworth, and M. P. Viner. *Training Effectiveness Evaluation of the Squad Engagement Training System (SETS)*. RR 1562. USA Research Institute for the Behavioral and Social Sciences, Alexandria, VA, 1990.

*No abstract available.*

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[Fish 1995a]
D. Fish. *Return on Investment Calculations for Indoor Simulation Marksmanship Trainer (ISMT).* Memorandum to M&S Benefits Task Force. Marine Corps Modeling and Simulation Management Office (MCMSMO), Quantico, VA, 1995.

The purpose of the ISMT is to enhance the combat training of Marines, and not just replace live fire with simulated rounds. The commander may wish to consider the results of a judicious application of the ISMT to a routine Marine Battle Skill Training (MBST) task (requalification). The offset of just one day of firing results in projected savings of $1.2 million in the first year of the program. In years two through five, projected annual savings are greater than $2.1 million. Complete recovery of acquisition costs is projected before the end of year four; projected cumulative savings at the end of year five exceed $3.2 million.

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[Fish 1995b]
D. Fish. *Return on Investment Calculations for Emerald Light: Instrumenting Individual Combat Entities*. Memorandum to M&S Benefits Task Force. Marine Corps Modeling and Simulation Management Office (MCMSMO), Quantico, VA, 1995.

The Emerald Light project potentially offers the Marine Corps a great deal of bang for the buck. The project proposes to instrument portions of the Marine Corps Air Ground Combat Center (MCAGCC) at 29 Palms, CA. In addition to the instrumentation infrastructure, equipment will be procured for 200 player units, including riflemen, tanks,

LAVs (light armored vehicles), and trucks. This instrumented training range will enable improved computer-aided exercises (CAX) at MCAGCC as well as linkage to the Army's National Training Center at Ft. Irwin, CA. A Rough Order of Magnitude analysis suggests that Emerald Light could reduce the costs of a CAX from $9.5M to $5.8M. With roughly 10 CAX per year, recovery of investment would be rapid. The improvement in the quality of Marine Corps training and joint Army-Marine Corps is not quantified.

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[Fish 1995c]
D. Fish. *Return on Investment Calculations for Deployable Forward Observer-Modular Universal Laser Equipment (DFO-MULE).* Memorandum to M&S Benefits Task Force. Marine Corps Modeling and Simulation Management Office (MCMSMO), Quantico, VA, 1995.

The Deployable Forward Observer-Modular Universal Laser Equipment (DFO-MULE) is a deployable, modular, distributed interactive simulation (DIS) compliant, PC-based system that provides basic, advanced and sustainment training for Forward Observers and Forward Air Controllers. Fire support operations involving Naval Gunfire, Artillery, and Close Air Support are simulated on this system. Assuming a 10% offset of live fire tasks, savings in ammunition expenditures realized by DFO-MULE can potentially recover the acquisition costs before the end of the second program year. The most expensive round, the $36,087.68 Copperhead, is excluded from the calculation. Several qualitative advantages are also cited.

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[Frost and Sullivan 1989]
Frost and Sullivan, Inc. *The US Military Trainer and Simulator Market: Vols. I and II.* January 1989.

This is a two-volume comprehensive report based on studies conducted by Frost & Sullivan. It provides detailed information regarding trainers, simulators, and associated markets. While trainers and simulators may play a vital role in the conduct of a wargame model simulation, there is a distinct difference between trainers and simulators, and wargames, models, and simulations. The report does not address wargames and simulations and therefore should not be used as a source document to evaluate trends or markets in that area.

Section One is the Executive Summary which provides a forecast of the US military market for simulators and other training devices (FY90 - FY94), a list of the top companies in this market (FY83 - FY88), and a high-level summary of the entire report. Section Two introduces the report's overall objectives, definitions, organization, coverage, sources of data, application, and scope. Section Three gives background information. Sections Four, Five, and Six, which make up the majority of the report, discuss in both quantitative and qualitative detail each Service's simulators and training devices; planned procurement; research, development, testing, and evaluation (RDT&E); competition; and contracts and forecasts. Section Seven summarizes the market for training devices related to the military market but funded by other agencies. Section Eight discusses technological trends. Section Nine profiles manufacturers of military simulators and other training devices. A useful glossary constitutes the Appendix.

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[GAO 1993]
General Accounting Office. *Army Training: Commanders Lack Guidance and Training for Effective Use of Simulations.* GAO, Washington, DC, 1993.

This study was conducted in response to a tasking from the Committee on Armed Services, House of Representatives, which stated, in part, "The Army faces many constraints on the field training exercises that it has traditionally used to prepare its forces for wartime missions. Funding for the ammunition, fuel, and maintenance required for these exercises has been reduced, and environmental concerns restrict the use of ranges and maneuver areas. In response, the Army has turned to simulations to supplement field training exercises." The report noted that at the brigade level and above, simulations can be used to improve the decision-making skills of senior battle officers before they command units in large-scale training exercises, and that at the lowest level, simulations can be used to develop the basic skills of individual soldiers. Exemplary simulations cited in the report were COFT (Conduct of Fire Trainer), used on tanks and Bradley Fighting Vehicles; MILES (Multiple Integrated Laser Engagement System), used to simulate direct fire weapons from rifles to tank and helicopter gunnery systems; and SIMNET (Simulator Networking), used to provide crew-, platoon-, and company-level training. The report concluded that simulations are not reaching their full potential because commanders lack adequate guidance and training in their effective use.

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[GAO 1991]

General Accounting Office. *Army Training: Computer Simulations Can Improve Command Training in Large-Scale Exercises.* GAO, Washington, DC, 1991.

This study was motivated by concern over whether simulation provides an adequate alternative to traditional large-scale military exercises. The GAO analyzed the 1990 REFORGER exercise (Return of Forces to Germany) in which extensive use was made of simulation, fewer U.S. troops participated, and emphasis was given to training staffs and leaders at higher organizational levels rather than lower-level units. Training for higher-echelon leaders, such as brigade, division, and corps levels, was made possible by extensive use of computer-assisted simulation. It was reported that a consensus exists among many military officials that computer-simulated exercises, such as REFORGER, offer the potential for effective training, particularly at higher organizational levels where the focus is on battle planning and command and control. Benefits of such training include an emphasis on battle planning, staff procedures, and command and control; more efficient use of training time; a focus on higher echelons that would otherwise be cost prohibitive; and lessened adverse environmental and political impacts. The 1990 exercise saved more than $4M in transportation and cargo handling costs as compared to costs historically documented. However, the study noted that comparing the costs of traditional and simulation-based exercises may not be meaningful because of differences in the type of training provided.

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[Garcia et al. 1994]

A. B. Garcia, R. P. Gocke, N. P. Johnson. *Virtual Prototyping: Concept to Production.* Defense Systems Management College, Ft. Belvoir, VA, March 1994.

This study represents the combined efforts of three military Research Fellows participating in an 11-month Senior Service College Research Fellowship program. The program was designed to provide a forum for the conduct of research in a subject of vital interest to the U.S. defense acquisition community. The research that supports this study was conducted during calendar year 1993. Simply stated, this study assesses and describes the current state of virtual prototyping. It focuses on leveraging virtual reality to "build" prototypes with computers, test their performance in a synthetic battlefield, conduct trade-off evaluations between existing, modified, and new systems, all before the actual construction of a prototype. The study is organized into an Executive Summary and six

chapters. The introduction, Chapter One, explains the objective, methodology, assumptions, and background of the study. Chapter Two explains the defense environment and the role of virtual prototypes. Chapter Three addresses the spectrum of synthetic environments. Chapter Four examines the application of synthetic environments to the acquisition process. A detailed account of synthetic applications is given in Chapter Five, while Chapter Six presents the study's summary and recommendations. There are useful appendices that list virtual prototype models and simulations, the points of contact for each one, a glossary, and a bibliography.

The body of literature on virtual prototyping is without extensive references to current applications in the defense industry: not because it is not being used but because each company considers virtual prototyping a key ingredient in its ability to compete. Thus, companies jealously protect the specifics of how they use virtual prototyping. As an example, Boeing developed its newest commercial aircraft, the Boeing 777, without building a physical mock-up. The digital prototype was designed and tested, then went straight to the design floor for construction. Boeing will not share its "how to" use of virtual prototyping. Throughout the text there are 2 tables, 71 figures, and 10 color plates that make this otherwise difficult subject more understandable. The study's literature review identified more than 500 articles of possible relevance. Ultimately, 150 of these sources were actually used in the preparation of the study and 113 are further cited in the bibliography.

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[Gates 1987]
S. M. Gates. *Appropriate Mix of Live Fire and Simulated Fire During Training.* CNA CRM 87-116. Center for Naval Analyses, Alexandria, VA, 1987.

Gates presents a small-scale review of studies to estimate the general benefits of TADSS and live fire to develop weapon system operator proficiency. The general conclusions are that training with simulated fire can develop the same skills as live fire, an increase in simulator practice time can translate into higher levels of operator proficiency, and only minimal amounts of live fire may be required to effect transfer of simulator training. As simulator training becomes more effective, more live fire practice can be replaced without degrading operator proficiency, but a certain amount of live fire will probably always be recommended to document the training transfer and convince the gunner that he is, in fact, a capable weapon system operator and not merely an expert at a realistic video game.

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[Gorman 1990]

P. F. Gorman. *The Military Value of Training.* IDA Paper P-2515. Institute for Defense Analyses, Alexandria, VA, 1990.

This paper was prepared in response to a NATO inquiry seeking to apply operational research to the contribution of military training and the overall effectiveness of the force. It presents the training vision of General Paul Gorman (USA Ret.), a former commander of the U.S. Army 8th Infantry Division. At a time when requirements for readiness were increasing and training resources were decreasing, he was among the first to introduce battle simulation to train and evaluate tactical Army units. This paper is of value to historic researchers of the early years of simulations or those looking for basic simulations applicable at the tactical level of combat unit training. General Gorman, considered one of the "founding fathers" of training simulations, has written an easily understandable study.

This document is a primer on the use of training simulations at the tactical level, and the author's architectural framework for training continues to be followed today. General Gorman writes, "The first battle of most wars fought by the Army of the United States was a disaster: a costly defeat or a Pyrrhic victory." This quotation is a timeless argument in favor of simulated training that is resource effective, and can be rehearsed repeatedly to improve combat readiness, refine necessary skills and strategies, and preserve the fighting forces. Gorman presents compelling evidence concerning the value of combat experience for survival and later success in combat, and makes the case that tactical engagement simulation provides the military with the equivalent of combat experience without its casualties. During World Wars I and II, inexperienced pilots had at best four chances out of ten of being shot down and fewer than 15% of pilots had a better than 50% chance of surviving their first combat. But with each successive victory, a pilot's survivability increased dramatically. A NATO review of German U-boat captains showed that 10% of them accounted for 45% of recorded sinkings. Early success in combat was correlated strongly with survivability. During the early years of the Vietnam war, about one U.S. fighter was lost for every two North Vietnamese MIGs; the ratio of victories to losses rose to 12.5:1 for Navy pilots after the Top Gun program, an engagement simulation, was established.

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[Grimes 1994]
V. P. Grimes. "Navy/Marine Corps Team Changes Training Focus." *National Defense* 129 (502) (November 1994): 26-27.

This article details simulation system's marketing trends in the Navy and Marine Corps. It provides readers with basic knowledge of training trends in the Navy Department triggered by changes in the threat, budget constraints, and Joint training and operational commitments. There are enough facts and figures in this two-page article to give the reader a basic knowledge of Navy and Marine Corps training trends as well as reasons for the direction training has taken in these services. It covers areas such as Zero-based Training and Educational Review, systems trainers, littoral warfare environment; organizational changes are given in just enough detail to provide an outline of the naval Services' training initiatives.

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[Hammond et al. 1993]
M. H. Hammond, D. R. Graham, and E. P. Kerlin. *The Role of Distributed Simulation in Defense Acquisition.* IDA Paper P-2902. Institute for Defense Analyses, Alexandria, VA, 1993.

This paper examines the role that distributed simulation could play in incorporating the latest design, engineering, manufacturing and support technologies, and management practices in DoD's acquisition system. These improved technologies and practices have allowed some of the most progressive commercial firms to reduce development time and costs by up to 50 percent. Three advances have made this possible: (a) the diffusion of new management approaches such as integrated product and process development (IPPD) and Total Quality Management (TQM); (b) rapid improvements in design and manufacturing technologies; and (c) the increased power of distributed communications networks linking dispersed elements of design teams. Discussions are provided on how commercial firms and defense programs have used distributed simulation technologies in conjunction with these advances to provide a basis for coupling simulation investments with acquisition process improvements. Specific investment areas are identified which would aid the DoD and its suppliers to adopt these advances.

[Hammond et al. 1995]
M. H. Hammond, B. Brykczynski, E. A. Feustel, A. N. Joglekar, J. J. Loughran. *Review of Defense Modeling and Simulation Office Projects and Activities for Fiscal Years 1992-1994.* IDA Paper P-3062. Institute for Defense Analyses, Alexandria, VA, 1995.

This paper provides a consolidated summary of those projects and activities sponsored by the Defense Modeling and Simulation Office (DMSO) during Fiscal Years 1992-1994. The projects were selected by a formal, community-wide process led by DMSO, whereas the activities were directly selected by DMSO. Representative projects and activities range from development of simulation protocols to participation in exercises to coordination of a DoD directive on M&S management. A total of 48 projects and 17 activities were reviewed. Summary descriptions for each project and activity are presented, including such information as the objectives, accomplishments, and benefits of the projects and activities. Aggregated information relating the projects and activities to common themes is also provided. In addition, the process by which the projects were selected is also described. This papers thus serves as a reference furnishing summary information on the DMSO projects and activities. Making information available in this way should help other parties identify results of the projects and activities that could be of use to them.

[Hawley and Christ, in press]
J. K. Hawley and R. E. Christ. *Assessing the Value Added of New Training Technologies.* ARI TR (TBD). USA Research Institute for the Behavioral and Social Sciences, Alexandria, VA, in press.

The authors present a value-added assessment model for Distributed Interactive Simulation (DIS) training. They applied portions of the model to the Multi-Service Distributed Training Testbed (MDT2) Plus. This testbed is designed to train Close Air Support (CAS) and counter air defense in multi-Service operations. The authors define "value added" by asking four questions: 1. Is the potential application *suitable*? 2. Is the application *effective*? 3. Is the potential application *superior* to conventional training methods? 4. Is this superiority operationally *relevant*? They detail and provide measurement concepts for each of the questions. In their test of the model, they address two of the assessment dimensions: suitability and estimated effectiveness. They conclude that MDT2 Plus is suitable for its intended purpose if it is not used for introductory CAS training, or as a complete substitute for field training. They also conclude that MDT2 Plus is potentially effective in training multi-Service CAS synchronization and coordination tasks.

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[Horowitz et al. 1992]
S. Horowitz, C. Hammon, P. Lurie, P. Brooks, and A. Rolfe. *The Cost-Effectiveness of Flying Hours and Simulators.* Briefing. Institute for Defense Analyses, Alexandria, VA, 1992.

The authors gathered and analyzed data relating to flying hours and simulator time and mission performance or safety. More than $10B per year is spent on flying hours but the appropriate mix of flying time and simulator time is unclear. A general conclusion from several different studies is that both flying hours and simulator time affect performance, but usually career flying hours have a greater effect than recent flying hours. Bombing and air drop accuracy data indicate that additional simulator hours seem to have a greater effect than additional flying hours, and simulator hours cost at most a third as much. Helicopter accident data indicate that both flying hours and simulator hours reduce accidents, but simulator hours do not increase expose to risk. The authors suggest that it may be cost effective to substitute small amounts of additional simulator time for flying time, but note that measures of proficiency used in analyses were incomplete and the authors were wary of carrying this too far.

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[Houck et al. 1991]
M. R. Houck, G. S. Thomas, and H. H. Bell. *Training Evaluation of the F-15 Advanced Air Combat Simulation.* AL-TP-1991-0047. Air Force Armstrong Laboratory, Williams AFB, AZ, 1991.

The evaluation investigated the utility of existing multiship simulation for training air combat tasks. F-15 pilots and air weapons controllers participated in four days of training in simulated air combat missions in an unrestricted combat environment that included multiple air and ground threats, electronic warfare, and real-time kill removal. After training, participants rated the value of training. Overall, participants indicated that simulation enhanced their combat readiness and was more beneficial in some areas than traditional unit training.

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[Hughes et al. 1988]
C. R. Hughes, W. G. Butler, B. S. Sterling, and A. W. Berglund. *M1 Unit Conduct of Fire Trainer: Post Fielding Training Effectiveness Analysis.* USA TRAC-WSMR TEA 16087. USA TRADOC Systems Analysis Activity, White Sands Missile Range, NM, 1988.

This analysis evaluated the training effectiveness of the M1 UCOFT. The evaluation included 369 tank commander-gunner pairs from 6 armor battalions in Europe. Training effectiveness was evaluated in terms of crew performance on Tank Table VIII. Results were (1) progress through the training matrix and, to some extent, more training time typically resulted in improved Table VIII performance; (2) the UCOFT was not a precise predictor of performance; (3) the UCOFT could make a substantial contribution to sustaining crew gunnery skills; and (4) users felt that the UCOFT improved home station gunnery training.

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[Hughes 1989]
W. P. Hughes, ed. *Military Modeling.* Second edition. Military Operations Research Society, Alexandria, VA, 1989.

This textbook, used at the U.S. Army War College with the endorsement of the Military Operations Research Society (MORS), describes the attributes of well-conceived military models, shows how models can contribute to the decision process, and cautions the reader that models can be misused and oversold. It is designed for the reader who is knowledgeable in military operations and the decision-making process, but who has only superficial acquaintance with the models that inform and contribute to the process. For the subject matter expert, *Military Modeling* serves as the primer for military modeling. The book begins with an Overview written specifically for the novice and proceeds to introduce the student to the subject of modeling with general readings in 15 technically oriented chapters. This work describes military models across all dimensions. Designed and written for senior individuals who are entering the field of military modeling, it serves as the transition piece from those who know about modeling to those who are expert in the field. The contributing authors represent leading practitioners of military modeling. Of note is the discussion of models' verification and validation; these often misunderstood concepts are examined in depth, clarified, and defined. For example, the author notes that all models are, by definition, invalid because they are, after all, abstractions of an actual activity. In addition to abstraction, which is the omission of some observable factors,

there is another concept that affects models: approximation. Approximation involves limits on the precision of calculation. The better the modeler is able to reduce the influences of abstraction and approximation, the better the model.

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[Irvine 1994]
G. M. Irvine. "Combat Training Can Be Done Pierside." *Naval Institute Proceedings* 120 (January 1994): 76-79. U.S. Naval Institute, Annapolis, MD.

This article describes the advantages of on-board training with a ship's own hardware using either the SQQ-89 Onboard Trainer (OBT) or an Interface Test Set (ITS) to provide training inputs. Highlighting exercises from 1992 and 1993, the article describes how these exercises demonstrated the effectiveness and efficiency of training in port using simulation and training devices in conjunction with a ship's own systems. It demonstrates the uses of simulation in education and training today, and is a good source of examples which would lend credence in the classroom.

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[Institute of Simulation and Training 1995]
Institute of Simulation and Training. *12th DIS Workshop on Standards for the Interoperability of Distributed Simulations. Volume 1: Position Papers.* IST, Orlando, FL, 1995.

This document is a compendium of 101 technical papers presented at the 12th DIS Workshop. It represents the very latest thinking for current distributed interactive simulation technology and innovation. The 15-page Table of Contents lists all titles, authors' names and organizations. A sampling of some of the more provocative titles includes "Strategies for Scaling DIS Exercises Using ATM Networks," "Qualitative and Quantitative Comparison of Images from Dissimilar Image Generators in Distributed Visual Simulation," "DIS Synthesis with Interactive Television: Revolution of the Educational Paradigm," and "An Algorithm for Presenting a Continuous After-Action Review Representation from Multiple Overlapping DIS Exercise Segments."

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[ITEC 1995]
*International Training Equipment Conference and Exhibition Proceedings.* N. Jackson and N. Cruz, compilers. ITEC, Ltd., The Hague, April 25-27, 1995.

This work contains papers and reports from the International Training Equipment Conference and Exhibition Proceedings held in The Hague, The Netherlands, April 25-27, 1995. Materials were submitted under the following general headings:

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|---|---|---|
| Training Performance | Computer Generated Forces - Environment | Aviation Training |
| Driving Simulation - Technical | Distributed Interactive Simulation | Virtual and Constructive Simulation |
| Driving Simulation - General and Applications | Audio-Visual Cues | Computer Based Training Applications |
| Unseen Services To Aviation | Multimedia Training Requirements | Simulation Training and Equipment |
| Synthetic Environment | Airline Training | Combat Training |
| Distributed Interactive Simulation Technologies | Flight Training Organization | Maritime Training |

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[JCS 1993]
Joint Chiefs of Staff. *The Catalog of Wargaming and Military Simulation Models.* 12th edition. U.S. Department of Defense, Washington, DC, 1993.

*No abstract available.*

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[Jolly and Ward 1995]
A. C. Jolly and R. C. Ward. *Cost Saving/Avoidance Benefits of Hardware-in-the-Loop Simulation and Distributed Interactive Simulation at RD&E Center, US Army Missile Command.* Research, Development, and Engineering Center, USA Missile Command, Redstone Arsenal, AL, 1995.

Jolly and Ward's report contains the details of the outcomes of selected use of Hardware-in-the-Loop (HWIL) and Distributed Interactive Simulation (DIS). They provide some examples of demonstrated benefits in cost savings and cost avoidance experienced in missile development programs supported by the Research, Development, and Engineering Center (RDEC).

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[Kernins et al.1990]
J. W. Kernins, N. K. Atwood, and J. T. Root. *Concept for a Common Performance Measuring System for Unit Training at the National Training Center (NTC) and with Simulation Networking (SIMNET).* ARI Research Report 1574. USA Research Institute for the Behavioral and Social Sciences, Alexandria, VA, 1990.

This report presents a concept for the design of a common performance measurement system for units training at the National Training Center (NTC) and units training with simulator networking (SIMNET). The measurement system included components from mission accomplishment, performance of critical tasks and expert judgment. The approach presented in this research is applicable when designing evaluations to compare different training systems.

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[Kraemer and Bessemer 1987]
R. E. Kraemer and D. W. Bessemer. *U.S. Tank Platoon Training for the 1987 Canadian Army Trophy (CAT) Competition Using a Simulation Networking (SIMNET) System.* Research Report 1457. USA Research Institute for the Behavioral and Social Sciences, Ft. Knox, KY, 1987.

The authors estimate the effects of SIMNET training based on observation and interviews, results of CAT competition, potential relationships between CAT results, and SIMNET training with other unit training. Findings suggest that SIMNET training may have helped units develop and improve their fire control distribution plans and helped unit leaders develop the command, control, and communications skills to effectively execute those plans during platoon battle runs. Other major contributing factors to CAT outcomes were conducting live fire battle runs and tank crew gunnery training on the M1 UCOFT (Unit Conduct of Fire Trainer). The most apparent shortcoming of the SIMNET that may have interfered with CAT training was in the M1's fire control system.

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[Lane and Alluisi 1992]

N. E. Lane, and E. A. Alluisi. *Fidelity and Validity in Distributed Interactive Simulation: Questions and Answers.* IDA Paper D-1066. Institute for Defense Analyses, Alexandria, VA, 1992.

*No abstract available.*

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[McIntyre and Salas 1995]

R. M. McIntyre and E. Salas. "Measuring and Managing Team Performance: Lessons from Complex Environments." In *Team Effectiveness and Decision Making in Organizations*, R. A. Guzzo and E. Salas, eds. Jossey-Bass, San Francisco, CA, 1995.

The authors present 20 principles concerning team training derived from simulator-based research of military teams. These were Navy tactical decision-making (TAC-DM) teams which make decisions under the stresses of time pressure and enemy threat. Taskwork (tasks performed by individual team members) is contrasted to teamwork (team interactions which improve the quality of team performance). Principles are grouped in terms of teamwork behaviors, team leadership, and roles of individual team members.

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[Morrison et al.1991a]

J. E. Morrison, E. H. Drucker, and D. A. Campshure. *Devices and Aids For Training M1 Tank Gunnery in the Army National Guard: A Review of Military Documents and the Research Literature.* ARI Research Report 1586. USA Research Institute for the Behavioral and Social Sciences, Alexandria, VA, 1991.

This report presents a review of military documents and the research literature on the devices and aids that could be to train and sustain gunnery skills and knowledge for use within the Army National Guard. Six gunnery skills training devices were examined on the basis of skill acquisition, retention, prediction of performance and transfer of training. The beneficial effects of partial functional overlaps of the devices were noted from both a learning and operational perspective.

[Morrison et al.1991b]
J. E. Morrison, D. A. Campshure, and E. L. Doyle. *A Device/Aid-Based Strategy for Training M1 Tank Gunnery in the Army National Guard.* ARI Research Report 1587. USA Research Institute for the Behavioral and Social Sciences, Alexandria, VA, 1991.

Training devices and aids can minimize constraints to on-tank gunnery training in the Army National Guard (ARNG). This report describes a strategy for employing devices and aids to train gunnery. Although specifically tailored to the needs of the ARNG, the discussion of methods should be useful to the design, development, and implementation of gunnery training in the Active Component and the U.S. Army Reserve.

[Morrison and Hagman 1994]
J. E. Morrison and J. D. Hagman. *A Device-Based, Time-Compressed Strategy for Army National Guard Tank Gunnery Training.* ARI Research Report 1012. USA Research Institute for the Behavioral and Social Sciences, Alexandria, VA, 1994.

This report describes a training strategy to reduce or compress the time needed to prepare for tank crew qualification on Table VIII through use of the Conduct-of-Fire Trainer (COFT) and Guard Unit Armory Device Full-Crew Interactive Simulation Trainer, Armor (GUARDFIST I). To compress time, the authors recommend that training (a) be focused on only gunnery skills needed for Table VIII qualification, (b) be given only to crews with demonstrated performance deficiency, and (c) be devoted to those Table VIII engagements found to be most difficult. Although the strategy was designed specifically for use by armor units of the U.S. Army National Guard, the rationale supporting its development could be applied to other situations where the type and availability of operational equipment and training devices differ.

[Nance et al. 1994]
J. F. Nance, R. P. Neisler, G. W. Steadman, and B. Wilhoite. *Simulation Offset to Live Fire Training: Test Plan Phase 3.* CIM-344. Center for Naval Analyses, Alexandria, VA, 1994.

*No abstract available.*

[National Simulation Center 1994]
National Simulation Center. *Training with Simulations: A Handbook for Commanders and Trainers*. Combined Arms Center, Fort Leavenworth, KS, October 1994.

This U.S. Army Command and General Staff College (CGSC) text was written for commanders and trainers to assist them in the planning and conduct of exercises involving simulations. It is designed to provide the reader with a basic introduction to simulations and insight into how command and control training simulations may be incorporated into an overall training strategy, specific guidance for their use in the development of a unit training strategy, general guidance into the planning of training exercises, and a view of future prospects in the area. *Training with Simulations* consists of 15 chapters, 7 appendices, and a glossary of abbreviations and terms. The National Simulation Center (NSC) prepared this book to meet the varied intellectual requirements of a primary and a secondary readership. *Training with Simulations* adequately serves as the primary textbook for a CGSC course and as reference material for non-training personnel engaged in command and control training simulations development. Although technical material is included to ensure the thoroughness of the topics presented, it would be wrong to characterize this book as a technical document. By design, NSC assumed the readers would possess very little inherent knowledge of the general subject of simulations. The text offers a basic foundation of the topic in straight-forward language, including a measured assortment of details that serve to clarify rather than distract. In the initial pages, this book clarifies a common confusion concerning the differences between simulations, models, simulators, and the varying types of models and simulations. Thereafter, the book continues to be a helpful training aid. The book is well organized for those new to the field and who seek to develop a strong point of departure for further reading or course work in simulations. Part I establishes a foundation in simulations. Part II addresses the question, "Why do we have simulations in the training environment?" Part III discusses a number of simulations currently available in the Army as members of the "Family of Simulations." Part IV presents the relationship between basic Army training principles and the employment of training simulations into a simulations strategy. Part IV is divided into two major chapters that discuss developments to the year 2012.

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[Neuberger and Shea 1995]

Thomas K. Neuberger and Dennis P. Shea. *Applying Synthetic Environments to Operational Training: A Perspective from Kernel Blitz 95.* CNA CAB 95-58. Center for Naval Analyses, Alexandria, VA, September 1995.

*No abstract available.*

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[Noble and Johnson 1991]

J. L. Noble, and D. R. Johnson. *Close Combat Tactical Trainer (CCTT) Cost and Training Effectiveness Analysis.* TRAC-WSMR-CTEA-91-018. USA TRADOC Analysis Command, White Sands Missile Range, NM, 1991.

This Cost and Training Effectiveness Analysis (CTEA) addressed the training capabilities and cost effectiveness of the CCTT, a simulator intended to train armor and mechanized infantry crewmen. The analysis concluded that the CCTT has the potential to train tasks relating to command, control, and communications; maneuver and navigation; teamwork and leadership; and, to a lesser degree, certain procedures related to gunnery, target acquisition, and driving. The analysis projected that the CCTT, when fielded, would be cost effective and that its life cycle costs would be paid back fully during its service life when acquired at either battalion or company level.

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[Null et al. 1993]

C. H. Null, and J. P. Jenkins, eds. *NASA Virtual Environment Research, Applications, and Technology.* National Aeronautics and Space Administration, Washington, DC, October 1993.

This paper describes the environmental research technology and its applications in NASA Centers, the potential roles it can take in NASA, and a strategic plan for NASA in the next five years. Virtual environment displays are interactive, computer graphics based, and head referenced, creating the illusion the user is remoted to another location. The paper contains a four-page Executive Summary, the Strategic Plan, and numerous one- or two-page listings of programs, research, and applications currently in use at NASA. Each listing provides a description of the system capability, system status and future plans, system architecture, location, point of contact, electronic mail address, voice and fax telephone numbers, and the offices with which coordination has been conducted. NASA has contributed to the current body of literature with this paper. It represents an overview

of the entire NASA virtual environmental effort and affords the reader a single-source document from which to initiate research. The simulations described in this white paper are sophisticated, state-of-the-art programs. The applications are not only current but demonstrate futuristic overtones.

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[ODUSD(R) 1995a]
Office of the Deputy Under Secretary of Defense for Readiness. *Military Manpower Training Report: FY 1996.* U.S. Department of Defense, Washington, DC, 1995.

*No abstract available.*

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[ODUSD(R) 1995b]
Office of the Deputy Under Secretary of Defense for Readiness. *Use of Simulation in DoD Training*. U.S. Department of Defense, Washington, DC, 1995.

This study was conducted in response to a U.S. Congressional request to DoD to determine the capabilities and limitations of simulation for training, its effect on training, DoD investments, and whether cost savings were possible though increased use of simulation. Some key findings are as follows. Regarding capabilities, simulations cost much less to use than operational equipment and can result in significant economies in training; enable people to do things that would otherwise be impossible, such as realistic simulations of combat and mission rehearsals; enhance safety because they can be used to do things that are too dangerous to practice with operational equipment; in some cases, provide performance data and better feedback to users than the systems they represent; overcome the practical limitations of live training, such as presenting a large force in a 360-degree battlefield; and help overcome environmental restrictions, which limit the ability to perform certain types of combat training, such as electronic warfare and realistic weapons employment training. Regarding limitations, the report indicated that simulations have a limited capability to represent the complex conditions involved in tactical aviation, such as the acceleration forces resulting from high-speed maneuvers and concomitant problems associated with spatial-temporal awareness; can cause a type of disorientation known as "simulator sickness" if visual and motion cues are not carefully synchronized; and still have technical hurdles to overcome in order to create a "seamless synthetic environment" capable of including all combat forces and platforms. Technical challenges include developing a common architecture, authoritative representations of environments and human behavior, and the full spectrum of weapon systems simulation. Simulation has proved to be both effective and efficient in providing training for a wide variety of tasks. The next generation of simulations presents opportunities for greater cost savings, but continuous and systematic feedback on the cost, effectiveness, and limitations of M&S technology is critical in developing successful strategic policies, plans, and investments strategies.

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[OTA 1994]

Office of Technology Assessment. *Virtual Reality and Technologies for Combat Simulation*. U.S. Congress, Washington, DC, 1994.

This analysis reviewed the state of the art of virtual reality (VR) technology for combat simulation, and made a number of observations on its current and potential cost effectiveness and in the future. Cost effectiveness is increasing as integrated circuits increase in density. The number of transistors in microprocessors is doubling every two years, the information storage capacity of memory chips is increasing similarly, and CD-ROMs and other media are now commonly used for high-capacity storage. Significant improvements are being made in several technologies supporting VR (e.g., flat panel display chips, LCDs (liquid crystal displays), micromechanical mirror arrays, parallel processing, networking, improved software); together these will allow new simulators to improve their speed and realism. Newer, high-density chips reduced the average cost of a fully immersive VR system (with head tracking, head-mounted display, and three-dimensional sound) from $100K in early 1991 to about $50K in 1993. It is forecast that cost will continue to decline. Similar trends are apparent in other computer-intensive simulators. High-tech simulation technology continues to become increasingly cost effective. VR challenges today include developing improved high-density, color flat-panel displays; fast head tracking; wideband networks with low latency; multilevel network security; automating object and world description for scene generators; and simulating infantry and noncombatants.

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[Operational Research and Analysis Establishment 1990]

Operational Research and Analysis Establishment. *Comparison of Conventional and Simulator Enhanced Tank Gunnery Training Methods*. Project Report 523. Operational Research and Analysis Establishment, Ottawa, Canada, 1990.

The report describes a series of war games performed with the JANUS simulation model to determine how training with M1 UCOFT (Unit Conduct of Fire Trainer) would influence combat effectiveness. Tank gunners trained with UCOFT fired their opening rounds about 25% faster than conventionally trained gunners. Based on estimated combat effectiveness, UCOFT training appeared to be of little, if any, benefit for LEOPARD C1 tanks when opposing heavily armored probable threats. When the model used LEOPARD II or M1A1 tanks, UCOFT-trained gunners killed significantly more opposing tanks than conventionally trained gunners. The difference in combat effectiveness is the result of the relatively greater firepower and survivability of the LEOPARD II and M1A1 as compared to LEOPARD C1.

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[Orlansky 1993]
J. Orlansky. *The Battle of 73 Easting and Ways to Future Victories.* NATO Panel 8 Meeting on Training Strategies for Networked Simulation and Gaming, NATO, November 1993.

"73 Easting" is a location in the Iraqi desert where the U.S. Second Armored Cavalry Regiment fought elements of the Iraqi Tawakalna Division. The battle occurred on the second day of the four-day ground war. The U.S. troops were outnumbered three to one but destroyed the opposing force, a heavy brigade in deliberate defense of an area the Iraqis had used for training exercises. In February 1992, some of the men who participated in the battle came to Washington to review and correct the record of the battle. Two retired officers asked them the following question: "None of you have ever been in combat before. How do you explain your great success in your first battle?" Battle participants responded, "Sir, this was not our first battle. This was our 15th battle! We fought three wars at the National Training Center (NTC), Fort Irwin, California, four wars at the Combat Maneuver Training Center (CMTC), Hoenfels, Germany; and a lot of other simulations like SIMNET, COFT, and BCTP. Yes, sir, we had been 'shot at' before. Many times. This war was just like out training."

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[Orlansky et al. 1994]
J. Orlansky, C. J. Dahlman, C. P. Hammon, J. Metzko, H. L. Taylor, and C. Youngblut. *The Value of Simulation for Training.* IDA Paper P-2982. Institute for Defense Analyses, Alexandria, VA, 1994.

This study examines the utility of simulation for training at individual, unit, and Joint force levels. The cost effectiveness of flight and maintenance simulators is well established, but a relatively limited amount of work has been done to establish the cost effectiveness of

simulation for more advanced individual training in units, for collective training in units, or for units in component or joint training. One finding is that simulators are cost effective for initial flight and maintenance training in institutions: they train as well as actual equipment and cost less to procure and use. This finding also applies to computer-based instruction as compared to traditional classroom instruction.

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[Orlansky and String 1977]
J. Orlansky, and J. String. *Cost-Effectiveness of Flight Simulators for Military Training. Volume I: Use and Effectiveness of Flight Simulators.* IDA Paper P-1275. Institute for Defense Analyses, Alexandria, VA, 1977.

The operating cost of flight simulators is estimated to be between 5 to 20% of the cost of aircraft. Many studies have shown that skills learned in flight simulators can be performed successfully in aircraft; consequently, the use of simulators for training can reduce flight time. At the time of this study, the cost effectiveness of flight simulators had been reported in only a few studies and their primary use was in undergraduate flight training. Their greatest potential for future savings is in transition and continuation flight training.

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[Orlansky et al. 1984]
J. Orlansky, M. I. Knapp, and J. String. *Operating Costs of Aircraft and Flight Simulators.* IDA Paper P-1733. Institute for Defense Analyses, Alexandria, VA, 1984.

This paper summarizes data comparing the operating cost of flight simulators and aircraft. The median cost ratio of simulators to aircraft was 8%.

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[Orlansky and String 1981]
J. Orlansky and J. String. *Cost-Effectiveness of Maintenance Simulators for Military Training.* IDA Paper P-1568. Institute for Defense Analyses, Alexandria, VA, 1981.

This study found that maintenance simulators are as effective for training as actual equipment trainers when measured by student achievement in school. Acquisition cost of simulators is typically less than actual equipment trainers. In the majority of cases examined, the cost to develop and fabricate one unit was less than 60% of actual equipment; the cost of fabricating a second unit was less than 20%. It was estimated that the acquisition and use of a maintenance simulator over a 15-year period would cost 38% as much as actual equipment. In studies where time to train was reported, simulators took 25 to 50% less time than actual equipment.

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[Oswalt 1993]

J. Oswalt. "Simulation and Gaming." *International Journal of Theory, Design and Research* 24 (2) (June 1993).

This special edition, a compendium of articles, summarizes recent military simulation and gaming applications, trends that affect their use, characterization and criteria of evaluation, and factors affecting their development (technologies, standards, and requirements). It also describes current organizations and implementations within the military services, academic institutions, and commercial enterprises. It concludes with a discussion of issues in combat simulation. The first article, "Current Applications, Trends, and Organizations in US Military Simulation and Gaming," is a review of military simulation and gaming. The next two articles, "Principles for the Design and Selection of Combat Simulations" and "Flexible Combat Modeling," are much more focused. "Flexible Combat Modeling" is of particular interest to the DMSO study. The author not only discusses the contemporary period but postulates about what will constitute necessary flexibility in the future. He also includes a brief section at the end entitled, "Advancing the State of the Art." Here he suggests two areas for research and design. The first is the ability to represent the differences among theaters of operation and forces. This effort requires defining how conflict would likely vary by region and then determining how models would need to be adjusted to reflect such differences. A consistent set of assumptions is yet to be designed in this area. The second area is the representation of new technologies. The author argues that new technologies or threats have been entered into models without adjusting the strategy or operations of either side, leading to significant but questionable effects on the overall combat outcomes. Overall, a systematic assessment of such changes in combat environment has not been performed by the military analysis community. These articles are reprinted from earlier publications.

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[OUSDAT 1994]

Office of the Under Secretary of Defense for Acquisition and Technology. *Task Force on the Use of Modeling and Simulation in Test and Evaluation.* U.S. Department of Defense, Washington, DC, June 23, 1994.

This report responds to the Defense Authorization Report for FY 94 regarding the use of modeling and simulation in test and evaluation. The response is structured in two sections consisting of (1) a description of the DoD policy regarding modeling and simulation investment and a progress report on implementation, and (2) a discussion of the analytical basis the DoD and the Services have used as an investment strategy. Appendix A reflects where modeling and simulation has realized cost savings or cost avoidance.

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[Randel et al. 1992]
J. M. Randel, B. Morris, C. D. Wetzel, and B. V. Whitehill. "The Effectiveness of Games for Educational Purposes." *Simulation and Gaming* 23 (3) (1992): 261-276.

*No abstract available.*

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[Regian et al. 1992]
J. W. Regian, W. Shebilske, and J. Monk. "A Preliminary Empirical Evaluation of Virtual Reality as Instructional Medium for Visual-Spatial Tasks." *Journal of Communication* 42 (4) (1992): 136-149.

*No abstract available.*

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[Pfeiffer and Dwyer 1991]
M. G. Pfeiffer and D. J. Dwyer. *Training Effectiveness of the F/A-18 Weapon Tactics Trainer (Device 2E7).* NTSC TR 91-1008. Naval Training Systems Center, Orlando, FL, 1991.

This study is a training evaluation of Device 2E7, F/A-18 weapon tactics trainer. Four maneuvers were examined, two each involving air-to-air and air-to-ground weapons delivery and tactics. Device 2E7 was effective for achieving learning objectives; skill acquired on the device transferred to the F/A-18 aircraft for each of the four tasks examined.

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[Schendel et al. 1984]
J. D. Schendel, F. H. Heller, D. L. Finley, and J. K. Hawley. *Use of Weaponeer Marksmanship Trainer in Predicting M16A1 Rifle Qualification Performance*. RR 1370. USA Research Institute for the Behavioral and Social Sciences, Ft. Benning, GA, 1984.

*No abstract available.*

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[Shlecter and Bessemer 1991]
T. M. Shlechter and D. W. Bessemer. *The Effects of SIMNET Role-Playing on the Training of Prospective Platoon Leaders.* ARI Technical Report 938. USA Research Institute for the Behavioral and Social Sciences, Alexandria, VA, 1991.

This investigation examines the relative value of having prospective armor platoon leaders engage in role-playing activities while using the simulator networking (SIMNET) training simulator. The results demonstrate that being in a platoon leadership position during SIMNET training leads to the highest performance evaluations. These findings imply that students should have direct experience in platoon leadership positions during their SIMNET training.

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[Schwab and Gound 1986]
J. R. Schwab and D. Gound. *Concept Evaluation of Simulation Networking (SIMNET).* TR 86-CEP345. USA Armor and Engineer Board, Ft. Knox, KY, 1986.

This early study of SIMNET was conducted to evaluate its capability to support platoon level command and control exercises to train individual and collective tasks. Three of the four platoons in each of the two groups, SIMNET and baseline, improved their performance between the first and second set of STXs (simulation training exercises). The SIMNET group improved from an average of 73% GOs on the pre-training STX to an average of 84% on the post-training STX. The baseline group improved from 59 to 65% pre- to post-training. The SIMNET group had a higher average score after both pre- and post-training STXs. The SIMNET group improved its average group score by 13% while the baseline group improved its score by 6%. Test players expressed the opinion that SIMNET was useful at training platoons in troop leading procedures, command and control, land navigation, and teamwork. They cited the ability to place platoons being trained throughout an exercise as one of the advantages of the system.

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[Seidel and Chatelier 1993]
R. J. Seidel and P. R. Chatelier, eds. *Advanced Technologies Applied to Training Design.* Plenum Press, New York, NY, 1993.

This is a collection of papers that is the product of a workshop sponsored by NATO's Defense Research Group Panel 8. The Group's overall purpose is to stimulate the defense application of research through the active exchange of information among the NATO

member nations. Panel 8 identifies training technologies that will maintain a capable and ready force during periods of reductions in military force structure and budgets. The workshop participants seek to leverage opportunities to apply these training technologies to nonmilitary roles of the future. The workshop focused on six technological areas: Authoring Systems; Models; Embedded Training and Simulation; Advanced Hardware Technology; Use of the Cognitive Approaches; and Expert Systems. The workshop also considered existing data structures that can provide both researchers and practitioners with ready sources of information. Authoring Systems is a high-cost driver for the most important factor of effective education and training. The workshop examined computer-aided techniques that offer alternatives to overcome this dilemma. The technological revolution in training is addressed in the next three sections. Models offer various solutions to reduce error from variations in approach, offer standardized formats, and provide interoperability for training and education. Embedded Training and Simulation offer the training managers alternatives to purchasing expensive military equipment. Advanced Hardware Technology is the critical, often limiting factor that this workshop addresses. Experience has shown that software advances often outpace hardware advances. The focus on Cognitive Approaches helps the participants understand the latest theoretical underpinnings to improve and further design improvements. The last section, Expert Systems, focuses more on application and use than on theory; the root of all expert systems is theory and it is, therefore, outside the scope of this work's examination. Each of the papers is a technical monograph addressing a subject of very limited scope. The introduction assists the reader put into perspective the intended outcomes from the collection of papers, which is the exchange of information on advanced training technologies and products that apply to NATO.

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[Signal 1993]
"Modeling Processes Offer Command and Control Aids." *Signal* (September 1993).

The author suggests new modeling methods may permit analysts to assess command and control capabilities in the same manner that combat forces are simulated. He argues that functional process improvements that can view all aspects of command and control will result in determining optimum use and benefit. This is a very technical article. The author quickly develops the details of functional process improvements on existing simulations and artificial languages. His recommendations are very specific, presenting a series of recommendations that will improve command and control capabilities. The application of these new technologies to training command and control, as well as improving command and control in simulations and wargaming, is apparent.

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[Simpson et al. 1995]

H. Simpson, W. D. West, and D. Gleisner. *The Use of Simulation in Military Training: Value, Investment, and Potential.* DMDC TR 95-007. Defense Manpower Data Center, Monterey, CA, 1995.

This study was conducted in response to a U.S. Congressional request to DoD to determine the capabilities and limitations of simulation for training, its effect on training, DoD investments, and whether cost savings were possible though increased use of simulation. It is an expanded version of the DUSD (R) (1995) report. Key findings include (1) simulation technology is advancing; (2) the Services have accepted and are using simulation and are making significant investments in them; and (3) simulations have proved to be cost-effective alternatives to traditional methods of training in many areas. Regarding the potential for increased use of simulation, the report drew the following conclusions.

Live simulation plays a vital role in preparing our forces for combat. A case can be made for increasing the amount of live simulation in the inter-Service and Joint area. Increased cooperation among the Services in this area has potential to improve the Joint training readiness of the force. Stand-alone single-system simulation is used heavily by the Services and is cost effective in many applications. The area with the greatest potential payoff for more application is probably in combat air crew training. With real aircraft, this type of training poses the greatest risk for loss of life and aircraft if mistakes are made. There is not adequate data to make a recommendation regarding the increased use of simulators in lieu of OPTEMPO (operating tempo) flying hours per aircraft, steaming days per ship, or ground vehicle miles. In general, the authors believe that the Services should be permitted to make this tradeoff on the basis of their assessment of the effect of simulation on the requirement to maintain readiness. Virtual simulation has the potential to enable Joint and inter-Service training in mission areas not being trained in sufficiently now (e.g., close air support). The technology permits coordinated training among the Services while individual Service elements remain at their home stations. This technology is new, though it appears to have great potential. Continued investment should be made in this area to develop, test, and refine the technologies to enable it to reach its full potential. The level of investment in constructive simulation is relatively modest in comparison with the other types of simulation. This does not, however, decrease its importance, especially in the command staff and Joint training areas. The Joint Staff and the various Unified and Specified Commands place increasing importance on the use of constructive simulations in their training programs. The authors believe that continued investment in constructive simulation based training is essential to the Joint readiness of the Total Force.

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[Spindler 1989]
G. B. Spindler. *AC/243 (Panel 7/RSG. 15)D/4 on the Military Value and Cost Effectiveness of Training.* NATO, Brussels, Belgium, 1989.

This document contains a number of case studies concerning the military value and cost effectiveness of training.

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[Swinsick 1995]
S. R. Swinsick. *Longbow Apache FCR RMAP Model Benefits.* RFI response. McDonnell Douglas Helicopter Systems, Mesa, AZ, 1995.

The benefits associated with the use of manned simulation in Force Development Test and Experimentation (FDT&E), shown in Table BIB-1, are numerous and quantified. FDT&E provided excellent points of comparison since the scenarios and activities conducted in the simulation and the field test were so similar. The FDT&E Phase II was about six times the cost of FDT&E Phase I. It required far more equipment, 24 times the personnel, took longer per trial to complete, and had the inherent risks associated with the operation of aircraft in a realistic environment.

**Table BIB-1. Longbow FDT&E**

| Resources | Phase I<br>Manned Simulation | Phase II<br>Field Test |
|---|---|---|
| Cost (O&M Army) | $712,000 | 4,049,000 |
| Equipment | 1 Simulator | 4 AH-64D<br>2 UH-60<br>14 M1 Tank<br>10 M3 Fighting Vehicle<br>2 2S6<br>20+ ADU<br>47+ Assorted Vehicle |
| Personnel (Government) | 27 | 663 |
| Mission Turn-Around Time | 2 hours | 6 hours |
| Data Reduction Time | 4 hours | 80 hours |
| Number of Trials | 32 | 16 |
| Test Period | 4 weeks | 6 weeks |
| Safety | No Risk | Moderate Risk |

FDT&E with the Longbow Integrated Training System has been the most comprehensive Longbow simulation effort to date. From individual training through record trials, many lessons were learned and quantified. The simulation provided the training necessary to make the crews proficient with the Longbow systems. During FDT&E, the crews were extremely competent and knowledgeable in the use of the Longbow systems and were able to rapidly correct when something went wrong.

A longer collective training period is recommended. The team standard operating procedure (SOP) must be second nature and crews must be working cohesively as a team before record trials begin. The crews conducted only three days of combat missions prior to record trials. At the end of the first week of record trials, the crews had reduced threat hits by 33% and by the end of week two the threat hits dropped another 30%. Moving more combat missions into the collective training phase would improve performance at the start of record trials.

The record trials identified some requirements which must be considered. The ability to rapidly modify scenarios or add new systems to the simulation is a necessity. Diversity in threat array composition and force movement prevents crew complacency with the missions. The threat force must be located to provide the attack helicopter company maximum maneuver space within the simulation database and to allow greater experimentation with tactics, techniques, and procedures (TTP). The simulation arena must remain as flexible and changing as the global environment around us.

As experienced in FDT&E, the simulator provides benefits in many ways. New tactics can be exercised against multiple situations with no risk to life or limb. The simulator allows the attack helicopter company to improve proficiency and increase safety before reaching the field by establishing and proving SOP and TTP.

Simulation supports the restructured Army's size, development objectives, and acquisition process. It requires less operational and support costs, no wear on active equipment, fewer test personnel, and no risk to life either human or machine. FDT&E has provided the quantifiable arguments for the application of simulation to training, test, and experimentation.

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[TECOM 1995]
USA Test and Evaluation Command (TECOM). *Virtual Proving Grounds (VPG) Modeling and Simulation Success Stories*. Unpublished manuscript. TECOM, Aberdeen, MD, August 1995.

**Firing Impulse Simulator (FIS).** The FIS at Aberdeen Test Center (ATC) simulates the recoil and trunnion loads and ballistic shock effects of firing impulses for tanks, and towed and self-propelled howitzers. The FIS delivers approximately 3 million pounds to a system to fully replicate an actual firing without the use of ammunition. The FIS project was a $6.9M investment in simulation technology. Simulated firing with the FIS was performed on the M1A2 trunnion test program in May 1994. Simulated firing with the FIS saved about $23M of cost avoidance for a typical trunnion bearing test. Test crew was reduced from 13 to 4 members. In addition, nonammunition firings resulted in significant time savings and significant environmental savings, reducing such effects as noise, toxic fumes, and blast overpressures. A one-year Trunnion Bearing Test is presently half completed to support the M1A2 Abrams and Armored Gun System (AGS). Future tests include the M1A1 Recoil Proofing Test and Composite Vehicle test.

**M830E1 Fuse Testing.** In support of the M830E1 test program, Yuma Proving Ground (YPG) developed a computer-based virtual test range simulation for evaluating tank versus helicopter engagements. Flight paths of the helicopter and trajectories of the prototype round were modeled based on actual flights and previous firings. Simulated helicopter engagements were conducted with an actual manned tank, with projectile (simulated) miss distance recorded for each engagement. Eighty such "virtual" firings were conducted. Then, the simulated engagements were verified by an actual engagement using a live round against a drone aircraft. The actual test cost was $260,000. This results in a cost avoidance of $1.5 M for not having to fire a complete test of live rounds against live targets. Although no further testing is currently scheduled, this technique can be enhanced for future large-caliber Air Defense applications.

**Moving Target Simulator (MTS).** The MTS test facility at ATC is designed to assess the ability of the M1A2 tank crew to track and simulate firing on images of simulated maneuvering targets. The MTS allows immersion of complete weapon systems (aircraft or ground based) into a moving visual target environment, and to investigate pointing and tracking performance of fire control systems. The simulator projects a laser spot target on the inside of a 100-foot hemispherical dome. With the test vehicle in the middle of the dome, evasive targets can be simulated for many different ranges. Use of the MTS is estimated to save $1.5M per year compared to field testing. Approximately 500 simulated engagements were completed in about 3 weeks during a test scenario, whereas in a live engagement it would have required two weeks just to set up and fire a single live round. The effect on acquisition time can be less time spent in testing and retesting. The MTS is now being refurbished for conducting gun positioning, weapon pointing, and gunner tracking testing for the M1A2, AGS, and 120mm mortar.

**Millimeter-wave Simulation/Test Acceptance Facility (STAF).** The STAF is a joint effort between the Redstone Technical Test Center (RTTC) and the U.S. Army Missile Command. It is a hardware-in-the-loop simulator for testing millimeter wave radar-guided missiles. The STAF provides testing of a fully assembled "live" missile with multiple computer-based test scenarios such as targets, ranges, and temperatures. The STAF allows a random selection of production munitions rounds from a Fly-to-Buy lot and tests these rounds in a real-time, non-destructive simulation. RTTC conducted a detailed cost tradeoff for the Longbow missile program. Some of the assumptions that entered into the analysis were that destructive firing of four missiles a month would be replaced by STAF method of testing six missiles per month by simulation, and destructive firing of four missiles per year would be used as an additional confidence builder and feedback to the model. If destructive test programs were performed on the Longbow, the yearly test cost would be $12.5M. The STAF test by simulation method, however, only costs $1.8[M] per year, resulting in a cost savings of $10.6M per year. The estimated $10.6M savings is only for the Longbow; the Patriot Advanced Capability-3 (PAC-3) and JAVELIN programs are planned to be tested in the STAF with similar expected savings.

**Aerial Cable Range (ACR).** The ACR at White Sands Missile Range (WSMR) employs a suspended aerial cable system that features highly repeatable test conditions, reusable targets, and fast turnaround of tests. The heart of the ARC is a 3-mile long suspended Kevlar cable that serves as the path for captive vehicles and supports test objects weighing up to 20,000 pounds. It is the longest unsupported cable span in the world. The initial cost of this range was $32.2M. The recently completed tests of the Joint Missile Approach Warning System (MAWS) resulted in a cost avoidance of $13.8M. Use of full-scale drone aircraft would have cost approximately $14.5M. The actual cost of the MAWS test using reusable, captive targets on the ACR was $700,000. Captive targets are not destroyed during testing on the ACR. A "heat source" hangs below the captive target so that the missile would aim at the heat source and not the targets. Other upcoming events include tests for the Apache (AH-64) Target Characterization in June 1995 and the Post Burnout testing of Infrared Sensors in July 1995.

**Test Item Stimulators (TIS).** The TIS at Electronic Proving Ground (EPG) provides non-radiating simulated digital message traffic input to challenge large network, computer-based command, control, and communications systems. Through the Test Control Center, inputs are time coded according to the mission or exercise scenario, and are variable and repeatable, as required. Through use of these stimulators, and the control model for operating the stimulators and test items, the cost of testing the Enhanced Position Location Reporting System (EPLRS) was reduced by $2M (30%). Savings were realized through improved test efficiency and reduction of number of operators required to support the testing. The TIS can be adapted to any communication system. It was also used for Mobile Subscriber Equipment (MSE) test, Joint Tactical Information Distribution System (JTIDS) test, and the Army Tactical Command and Control System (ATCSS) operational test.

**Trajectory Sense and Destroy Armor (SADARM) Simulation.** Real-time tracking data from range radars are used to model the ballistic simulation for the SADARM projectile trajectory to provide sufficiently accurate pointing data to target area instrumentation. This real-time optimal estimation software enables the downrange auto-trackers to acquire and track the incoming projectile and quickly transition to acquire critical end-game data on SADARM submunitions upon dispensing from the projectile. This new tracking capability has avoided $12M in instrumentation cost.

**Patriot Simulation Program.** The testing of PAC-3 hardware and software is supported by several models and simulators which reduce the requirement for launching targets, firing test missiles, and telemetering flight data. The PAC-3, being in the early stages of the development, has not entered U.S. Government technical testing. It is anticipated that once testing begins, a considerable amount of savings may be realized through flight mission simulation in lieu of actual firings. Each flight can be simulated numerous times to increase the confidence level of flight test performance without the use of live missiles, targets, instrumentation, and some data reduction expense. Although the Patriot modeling and simulation capabilities belong to either the Patriot Project Office or the Prime Contractor, TECOM will interface with these capabilities during anticipated virtual testing. At about $750,000 per launch of a Patriot missile, modeling and simulation are essential to the PAC-3 test program. In addition:

1. The Guidance Test and Simulation Facility is a full hardware-in-the-loop guidance simulator for the Patriot system, providing endgame geometry and miss distance in lethality analyses.

2. The Flight Mission Simulator provides a controlled environment of various simulated target signature and electronic countermeasures inputs to the system surveillance function, as well as simulated missile responses for the guidance function.

3. The Multi-function Simulation models Patriot search, tract, and engagement capabilities under radar loading.

4. The PAC Simulation provides a high-fidelity digital simulation of the surveillance function, missile dynamics, and lethality function for pre-flight predictions and post-flight reconstruction of flight tests.

5. The Counter Anti-Radiation Missile is a digital simulation of anti-radiation missile performance against the Patriot system.

**Physical Simulation of Bridge Crossing.** Traditionally, bridge durability testing is conducted by performing multiple crossings of vehicles. This method requires 12 weeks to conduct 3,000 crossings and costs $325,000. Bridge durability tests are now conducted using a mixture of actual and simulated crossings. ATC conducted the bridge crossing using actual equipment and vehicles that were instrumented to measure physical characteristics, and simulations were conducted using a physical bridge crossing simulator at Fort Belvior, VA. This new simulated test method reduces the time to nine weeks and costs to $110,000. During future use of the simulator, particularly for unique foreign bridges, this mix of live and simulated testing will be conducted exclusively at Aberdeen.

**Vibration Test Facility (VTF).** A long-established use of simulation in testing is the simulation of the natural and induced environments to which Army materiel is subjected. One such environment is vibration. Tanks with dummy ammunition are driven around and instrumented to measure the vibration levels. Those profiles are simulated with shaker tables at the VTF. It would take six months of field testing to subject tank ammunition to the transport vibration during its typical life cycle. At $1,200 per tank hour, doing this testing "live" would be prohibitive. Instead, 24 hours of transport simulation on a "shaker table" subjects tank ammunition to expected life cycle transport vibration. The VTF is also used to conduct tests where other components (i.e., radios, power units, heater units, environmental conditioning units, and autoloader equipment) are subject to various driving conditions. In both applications, increased simulation capabilities are reducing costly field testing.

**Joint Precision Strike Demonstration (JPSD).** Redstone Technical Test Center instrumented the Multiple Launch Rocket System (MLRS) Launcher, acquired weapon system performance data, and analyzed the data from the JPSD mission. In addition, WSMR successfully fired live Army Tactical Missiles as part of the distributed JPSD, using interactive live, constructive, and virtual simulation at various sites to develop an Army sensor-to-shooter, precision, deep-strike capability.

**Combined Arms Synthetic Experiment (CASE).** The CASE is a concept of linking two test centers to conduct live, virtual, and constructive simulations. This concept was successfully demonstrated in December 1994. In the CASE demonstration, real weapon systems operating at YPG and WSMR were synthetically fused with a JANUS Warfighting model, using Distributed Interactive Simulation protocols. Three-dimensional displays were generated based on the merged data to provide high-resolution visualization of the experiment in near real time. In addition, the injection of the real entities into the constructive simulation required the transformation of all live entities onto the terrain employed by the model. Pieces and modules of this capability are being developed. This capability should be fully operational in 1998 as part of the VPG. The CASE concept demonstrated the capability to support the Force XXI initiative, Advanced Warfighting Experiments, Advanced Technology Demonstrations, and Joint Service Integration Exercises. A CASE II is planned that will demonstrate additional capabilities and highlight tri-Service applications at the Major Range and Test Facility Base (MRTFB).

**3-D Virtual Test Range (VTR).** (ongoing). The VTR is generate from the Defense Mapping Agency's Digital Terrain Elevation Data Level II (30 square meter resolution) merged with weapon system models, human-in-the-loop, and hardware-in-the-loop for simulation of weapon system engagements. The VTR includes the Combine Arms Synthetic Experiment which uses Sensor Data Fusion (SDF). The SDF allows Virtual Reality Display of systems where optics fail, e.g., missile cruising at 140,000 ft.

**Integrated Radar and Infrared Analysis Modeling (IRIAM)** (ongoing). The IRIAM is a tri-Service program. It generates three-dimensional graphics for the representation of test data, real-time visual test reports, and flight test reports. The tri-Services are incorporating the Navy infrared modeling software, Air Force aircraft models and weather effects stimuli, and Army virtual display and range control software.

**Situational and Reality Display System (SARDS)** (ongoing). The SARDS consists of the VTR interfaced to the Global Positioning System Time Space Position Information equipment to provide real-time tracking to identify location and status of selected aircraft, vehicles, etc.

**C-17 Airdrop** (ongoing). The results of live airdrops at YPG are being used to model the airdrop characteristics of the C-17 Globemaster III.

**Dynamic Infrared Scene Projector (DIRSP)** (ongoing). The DIRSP is a new test technology concept that projects synthetic infrared imagery into the sensor entrance aperture. This system and the imaging infrared sensor are analogous to television and the human eye. The DIRSP, when integrated with existing models and simulation techniques, will bring "field testing" into the laboratory by supplying synthetic infrared field test environments for operational evaluation of imaging infrared sensors, subsystems, and systems.

**Covert Remote Electronic Warfare Simulator (CREWS)** (ongoing). The CREWS concept is based on replacing the use of high power, broadband jammers to simulate electronics warfare threat systems with a continuous wave tone generator of moderate power. This tone generator is used to radiate a signal of known amplitude in or near the frequency of jamming interest. The CREWS is mounted in either an airborne or ground platform to represent the real threat. For the JTIDS analysis, at least three "good" data points for each jamming condition are required. On an average, a field jamming test requires three flights to get a single valid data point. A live field jamming test for a single jamming condition would cost approximately $52,000. Using the CREWS, the aircraft will be flown one time and the CREWS will record the control tone's received signal level (RSL); subsequent data points will simply require playing back the recorded RSL information through the CREWS. The CREWS jamming test will cost only $5,000. CREWS modules are being produced in FY95 to instrument the Enhanced Position Location Reporting System (EPLRS), Mobile Subscriber Equipment (MSE), Joint Tactical Information Distribution System (JTIDS), and Single Channel Ground and Airborne Radio.

**Environmental Issues Guide for Heuristic Testing (EIGHT)** (ongoing). The EIGHT is a knowledge base of how environments affect materiel systems. The EIGHT is a unique tool that looks at the effects of environments on materiel systems, not effects of systems on the environment. EIGHT arranges information in a four-dimensional matrix with about 200,000 cells. Each cell consists of 4 climatic regions (e.g., cold, desert, tropic, and temperate), 50 environmental factors in 4 categories (e.g., natural, induced, constructed, and battlefield), 10 analysis areas (e.g., operability, safety, vulnerability), and 100 mission or commodity areas (e.g., air defense, aviation, command and control). This database provides ground truth for the VPG to define interaction of the test item and the environment, and also provides historical test results for different commodity systems and environmental conditions. It, therefore, provides lessons learned from these tests so that mistakes are not repeated and future testing is better focused on relevant parameters whether live or simulated.

**HELLFIRE Simulation** (ongoing). The Laser Designator Weapon System Simulation (LDWSS) is accredited for use to extrapolate HELLFIRE weapon system performance based on subsystem and component level testing. The LDWSS model is being upgraded and modified to allow for higher resolution (i.e., discrete component) effects analysis.

**Target Acquisition Model Improvement Program (TAMIP)** (ongoing). Models undergoing improvement in the TAMIP include millimeter-wave, infrared, visible, and acoustic capabilities. The enhanced models provide an objective means for comparing the vulnerability of vehicles as it relates to detection on the battlefield. The models are used for quantifying the value added when vehicle signatures are reduced, and to drive requirements for signature specification of future vehicles.

**Air Force AMRAAM Test Cost Savings.** During the last eight years, more than 130 DT&E missiles have been launched from test aircraft against drone aircraft. In addition, approximately 45 FOT&E missiles have been launched out of a planned total of approximately 65 FOT&E missiles. Only 8 live warheads have been used in the approximately 175 launches to date. The end-game effectiveness model, SHAZAM, has been successfully used to predict and subsequently to assess the lethality of each missile at end game.

This has resulted in a direct program savings of approximately $250M in drone aircraft costs alone because very few of the drones were damaged by warhead blast or fragments since only eight live warheads were used. In most cases, the $2.5M drones were able to be returned safely and used repeatedly. Table BIB-2 depicts the Return on Investment (ROI).

**Table BIB-2. AMRAAM Test Costs Savings ROI**

| | | | |
|---|---|---|---|
| Model Development: | 4 people x 2 yr x $125K/yr = | $1.0M | |
| Analysis Support: | 4 people x 8 yr x $125K/yr = | $4.0M | |
| Lethality Tests: | Range time and people = | +$1.5M | |
| Total Investment: | | $6.5M | |
| Direct Savings: | | $250.0M | |
| ROI: | | $250M/$6.5M = | 38 |

Other, less tangible benefits were as follows:

- No more F-106 aircraft suitable to be "droned" remain at Davis-Monthan AFB. Drones are now being made from F-4 aircraft and it would be difficult to support a missile flight test program if drones were not returned for reuse.
- The environmental impact on the Gulf of Mexico would be significant if hundreds of drone aircraft with leaking fuel tanks were crashed into the water. The use of lethality modeling with SHAZAM precludes this environmental problem.
- In actuality, the use of simulation permits the assessment of the entire end game, including the fly-by which would be denied if the warhead were detonated and the telemetry ceased to be transmitted. The use of simulation permits collection of these useful data after the warhead would have detonated.

**GBU-28 Precision Guided Weapon Test Savings.** The GBU-28 was developed at Eglin AFB, FL, in less than six weeks in response to an urgent need during the Gulf War. The short time did not permit any of the normal testing which usually accompanies any weapon development program. Consequently, the program management relied almost exclusively on lethality and vulnerability modeling to design and predict the performance of the new weapon system

The depth of penetration into subterranean structures was calculated using analytically derived penetration equations. One drop test of an inert GBU-28 was conducted on one type of soil to check the model; however, the primary purpose of the drop test was to verify the structural integrity of the steel case. The performance of the GBU-28, the depth of penetration, the lethality of the warhead in a new case, and the vulnerability of the targets were predicted successfully by lethality and vulnerability models. Without any prior drops of a live GBU-28, live GBU-28 weapons were dropped during the air war based on the confidence in current lethality and vulnerability models.

**Mk Series Bomb Fragment Data.** The Mk-84 general purpose bomb was retrofitted by the U.S. Air Force to have the option for either tail or nose fuzing or both. Arena tests were conducted at a cost of more than $400K to determine the difference in fragment spray patterns resulting from nose and tail fuzing. Based on these tests, lethality modeling techniques were developed to model the lethal fragment spray pattern. This, in turn, permitted both the Mk-82 and the Mk-83 general purpose bomb fragment spray patterns to be characterized without the expenditure of nearly $900K for additional arena tests. Table BIB-3 depicts the ROI.

**Table BIB-3. Mk Series Bomb Fragment ROI**

| | | | |
|---|---|---|---|
| Model Development:<br>Analysis Support: | Used JMEMS (sunk cost) =<br>2 people x .33 yr x $125K/yr = | $0.0K<br>+$82.5K | |
| Total Investment:<br>Direct Savings:<br>ROI: | | $82.5K<br>$900.0K<br>$900K/$82.5K = | 11 |

**Determination of BLU-109 Performance Envelopes.** When the BLU-109 was under development by the U.S. Air Force, it was necessary to conduct numerous drop tests of the weapon from an aircraft to determine the limits of impact angle, impact speed, and angle of attack which would permit successful penetration (without ricochet or partial penetration) of concrete surfaces such as runways. More than 80 tests at approximately $50K per drop were planned to obtain the required data.

Program analysts recommended the use of an analytical technique to reduce the number of drops from 80 to only 15 while still providing the required data to assess the lethality of the BLU-109 warhead throughout the performance envelope. This use of lethality modeling resulted in a one-time cost savings of more than $3M on this one weapon system. Table BIB-4 depicts the ROI.

**Table BIB-4. BLU-109 Performance Envelope**

| | | | |
|---|---|---|---|
| Model Development:<br>Analysis Support: | Integral with analysis =<br>2 people × 0.33 yr × $125K/yr = | $0.0K<br>+$82.5K | |
| Total Investment:<br>Direct Savings:<br>ROI: | | $82.5K<br>$3.0M<br>$3.0M/$82.5K = | 36 |

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[TILV 1995]
*DoD FY95 Master Plan for Target Interaction, Lethality and Vulnerability (TILV) Science and Technology (S&T) Programs. Volume I: Classical Ballistic Threats*. U.S. Department of Defense, Washington, DC, May 4, 1995.

**Air-to-Air Missile Engagement Analysis.** Beginning in 1980 the Air Force conducted an air-to-air missile engagement analysis called ACEVAL/AIMVAL which involved multiple aircraft in mock aerial duels. This effort cost more than $50M and required more than three years to complete.

A few years later, the AMRAAM Program required similar but additional data on the effectiveness of AMRAAM when used in conjunction with short-range missiles in aerial combat situations. Program analysts successfully convinced the program management that the required data could be obtained without the costly flight tests by using lethality modeling combined with aerial engagement modeling.

As a result, the AMRAAM Operational Utility Effectiveness analysis was conducted for $20M in two years, a savings of $30M and one year. One added advantage was that three times as many engagements were analyzed than would have been done in mock combat. Table BIB-5 depicts the ROI.

**Table BIB-5. Air-to-Air Missile Engagement Analysis ROI**

| | | | |
|---|---|---|---|
| Model Development:<br><br>Analysis Support: | Single cost includes both model development and analysis over a two-year period | $20.0M | |
| Total Investment: | | $20.0M | |
| Direct Savings: | Test costs not incurred = | $50.0M | |
| | 200 people × 1 yr × $125K/yr = | $25.0M | |
| Total Direct Savings: | | $75.0M | |
| ROI: | | $75.0M/$20.0M = | 4 |

**Wide Area Anti-armor Munition (WAAM).** The Air Force conducted developmental work on this system in the early 1980s but did not continue into full-scale development or production because lethality analyses showed that the system could not obtain the required kills per pass to make the system cost effective. The cancellation of this program was based on lethality analysis and resulted in estimated cost savings of $30M for the planned full-scale development effort. Table BIB-6 depicts the ROI.

**Table BIB-6. Wide Area Anti-armor Munition ROI**

| | | | |
|---|---|---|---|
| Model Development: | Integral with analysis = | $0.00M | |
| Analysis Support: | 6 people × 1 yr × $125K/yr = | +$0.75M | |
| Total Investment: | | $0.75M | |
| Direct Savings: | | $30.00M | |
| ROI: | | $30M/$0.75M = | 40 |

**Hypervelocity Missile.** The Hypervelocity Missile program was terminated in the early stages of full-scale development, based on an analysis using lethality models which indicated that the payoff would not be as great as expected during the initial planning effort. The cancellation of this effort was based solely on a lethality analysis and resulted in an estimated cost savings of $10M for the remaining full-scale development effort. Table BIB-7 depicts the ROI.

**Table BIB-7. Hypervelocity Missile ROI**

| | | | |
|---|---|---|---|
| Model Development:<br>Analysis Support: | Integral with analysis =<br>4 people × 1 yr × $125K/yr = | $0.00M<br>+$0.50M | |
| Total Investment:<br>Direct Savings:<br>ROI: | | $0.50M<br>$10.00M<br>$10M/$0.50M = | 45 |

**Intelligence Shelter Attack Submunition (ISAS).** The German government proposed a joint development effort with the United States to develop ISAS in 1987 for a total development cost of approximately $80M. After setting up a joint program office at Eglin AFB, FL, and signing the appropriate agreements, a detailed cost-effectiveness analysis was conducted using lethality models to determine the payoff of the ISAS to the U.S. Air Force if it were developed. The results of the analysis clearly showed that the system would not perform under all conditions and would not be advantageous to the Air Force. Thus the program was canceled solely upon the results of a lethality analysis with a resultant savings of $40M, the Air Force share for the proposed development effort. Table BIB-8 depicts the ROI.

**Table BIB-8. Intelligence Shelter Attack Submunition ROI**

| | | | |
|---|---|---|---|
| Model Development:<br>Analysis Support: | Integral with analysis =<br>4 people × 1 yr × $125K/yr = | $0.00M<br>+$0.50M | |
| Total Investment:<br>Direct Savings:<br>ROI: | | $0.50M<br>$10.00M<br>$10M/$0.50M = | 45 |

**Kinetic Energy Penetrator (KEP).** The U.S. Air Force developed a working version of a new runway penetrator called the Kinetic Energy Penetrator (KEP) which was ready for production in 1980. At the request of the program management, a tiger team was convened to determine the suitability of the system for production. After a review of the program and the completion of a detailed effectiveness analysis using lethality models of the system, the program was canceled. The technology was set on the shelf and the Air Force saved a minimum of $50M in production costs which were never incurred. Table BIB-9 depicts the ROI.

**Table BIB-9. Kinetic Energy Penetrator (KEP)**

| | | | |
|---|---|---|---|
| Model Development: | 8 people × 3 mo × $125K/yr = | $0.25M | |
| Analysis Support: | 16 people × 3 mo × $125K/yr = | $0.50M | |
| Range Tests: | Range time and people = | <u>+$0.30M</u> | |
| Total Investment: | | $0.75 | |
| Direct Savings: | | $40.00M | |
| ROI: | | $40M/$0.75M = | 53 |

**JP-233 Runway Attack Munition.** The JP-233 was a joint development effort conducted with the United Kingdom during the late 1970s. After spending several millions in the development costs with the United Kingdom, the program was finally ready for production in the early 1980s. Before commitment to production, the U.S. Air Force commissioned a study to determine the cost effectiveness of the JP-233 for Air Force use. The resulting analysis using both lethality and vulnerability (L/V) models clearly showed that the system was not cost effective for Air Force use. The use of L/V modeling in this case resulted in the U.S. withdrawal from the program and saved the Air Force more than $50M in production costs. Table BIB-10 depicts the ROI.

**Table BIB-10. JP-233 Runway Attack Munition**

| | | | |
|---|---|---|---|
| Model Development: | 4 people × 3 mo × $125K/yr = | $0.15M | |
| Analysis Support: | 20 people ( 3 mo ( $125K/yr = | $0.65M | |
| Range Tests: | Range time and people = | +<u>$0.30M</u> | |
| Total Investment: | | $1.10M | |
| Direct Savings: | | $54.00M | |
| ROI: | | $54M/$1.10M = | 49 |

**Boosted Kinetic Energy Penetrator (BKEP).** After withdrawing from the JP-233 program, the U.S. Air Force spent several years and millions of dollars developing its own runway defeat munition, called BKEP. After completion of full-scale development in

1987, continuing analysis of the BKEP's effectiveness by Air Force analysts using runway vulnerability models resulted in the determination that the BKEP would not be able to defeat some of the new runway designs being installed at the Warsaw Pact air bases. Based primarily on the results of this vulnerability analysis, the BKEP program was canceled with an estimated $130M savings in production costs alone. Table BIB-11 depicts the ROI.

**Table BIB-11. Boosted Kinetic Energy Penetrator ROI**

| | | | |
|---|---|---|---|
| Model Development:<br>Analysis Support:<br>Range Tests: | 4 people ( 6 mo ( $125K/yr =<br>12 people ( 1 yr ( $125K/yr =<br>Range time and people = | $0.25M<br>$1.50M<br>+$1.00M | |
| Total Investment:<br>Direct Savings:<br>ROI: | | $2.75M<br>$130.00M<br>$130M/$2.75M = | 47 |

JAVELIN Antitank Guided Missile. In the mid-1980s, the Army initiated development of a new man-portable antitank guided missile to counter recent changes in the armor threat. Soviet tanks had become more heavily armored, and it was clear that a new warhead technology was needed, and that an unconventional flight trajectory was required to deliver the warhead against the "softer" portions of a target. Without these advanced technologies, it was not possible to achieve the desired lethality within acceptable weight constraints.

Using flight simulation models and terminal lethality models, various delivery strategies and warhead technologies were evaluated. In this way, the best design approach was identified without destructive testing. Further, the required warhead size was determined by parametrically varying the size and computing kill probabilities.

By contrast, when the U.S. Army started development of its first antitank guided missile, the Shillelagh, it was not known what warhead size was needed to defeat the threat tanks of the day, and no models were available to address the question analytically. It was necessary to conduct a rather large experiment in which a scaled family of warheads were fired against tanks to observe the lethality as a function of size. One hundred twenty warheads were fired. If it were necessary to conduct such an experiment today, the cost would be in the neighborhood of $10M plus the cost of the target tanks. Thus, it is conservatively estimated that analytical simulation for the man-portable anti-tank guided missile saved at least $10M. Table BIB-12 depicts the ROI.

**Table BIB-12. JAVELIN Antitank Guided Missile ROI**

| | | | |
|---|---|---|---|
| Model Development:<br>Analysis Support: | 1 person ( 6 mo ( $125K/yr<br>6 people ( 9 mo ( $125K/yr = | $0.06M<br>+<u>$0.56M</u> | |
| Total Investment:<br>Direct Savings:<br><br>Total Direct Savings:<br>ROI: | <br>Test costs =<br>Tanks saved = 8 × $0.50M = | $0.62M<br>$10.00M<br>$4.00M<br>$14.00M<br>$14M/$0.62M = | <br><br><br><br>23 |

**M2 Bradley Fighting Vehicle System.** When the U.S. Army began development of the M2 Bradley Fighting Vehicle System, it faced a unique problem. The Army had never had a vehicle of this type, i.e., a vehicle which both transports an infantry squad and possesses significant firepower. While the intended tactical role of the vehicle was defined, there was no basis in experience for selecting the vehicle characteristics that would best serve the planned tactical role. The only experimental approach to the problem was to design and construct several prototypes and subject them to field testing at a cost of tens of millions of dollars.

Using analysis techniques, it was possible to address the issues analytically and save nearly all of this cost. Preliminary design concepts were sought from industry and from government with different design features. Each of these designs was evaluated analytically in terms of vulnerability, mobility, firepower characteristics, estimated cost, and logistic burden. With the results of these evaluation as inputs, the combat effectiveness of each design was estimated by use of a combat simulation model. The results of these evaluations allowed the Army to select the best vehicle for engineering development on a stronger basis than had been possible on any previous occasion and at an estimated savings of tens of millions of dollars. Table BIB-13 depicts the ROI.

**Table BIB-13. M2 Bradley Fighting Vehicle ROI**

| | | | |
|---|---|---|---|
| Model Development:<br>Analysis Support: | 2 people × 6 mo × $125K/yr<br>6 people × 1 yr × $125K/yr = | $0.13M<br>+$0.75M | |
| Total Investment:<br>Direct Savings:<br>ROI: | | $0.88M<br>$30.00M<br>$30M/$0.88M = | 34 |

**Abrams M1A2 Tank Vulnerability Testing.** The requirement for ballistic vulnerability testing on fully operational Abrams tanks was reduced by conducting vulnerability computer modeling to predict damage from penetrating threats before "Controlled Damage" tests were conducted. In effect, the computer predictions permitted the damaged components to be identified and disabled in the Controlled Damage tests, and the tests permitted the degradation of the system in combat to be determined without damage to the total Abrams vehicle. Costs for repair of ballistic damage to one Abrams can run as high as $1.5 million per shot if damage were catastrophic. For a series of 20 Controlled Damage tests, the total cost was $80K, compared with a potential loss of $30M for 20 tests on the full-scale Abrams. The 20 Controlled Damage tests, based on computer simulations to predict damage, cost only $80K, which was a savings of $29M. Table BIB-14 depicts the ROI.

**Table BIB-14. Abrams M1A2 Vulnerability ROI**

| | | | |
|---|---|---|---|
| Model Development:<br>Analysis Support:<br>Controlled Damage Tests: | <br>6 people × 1 yr × $125K/yr =<br>20 tests × $4K/test = | $1.00M<br>$0.75M<br>+$0.008M | |
| Total Investment:<br>Direct Savings:<br>ROI: | | $1.83M<br>$30.00M<br>$30M/$1.83M = | 16 |

**Block 3, M1A2 Abrams Tank.** During the development of the Block 3, M1A2 Abrams tank, an analysis of the radical front-engine tank design was conducted to assess the vulnerability of the design. The results of the analysis clearly showed the new design to be very vulnerable to certain threats which Desert Storm data proved to be correct. As a result, a very costly development program was terminated with a savings conservatively estimated to be more than $100M for development. Table BIB-15 depicts the ROI.

**Table BIB-15. Block 3, M1A2 Abrams Tank Design ROI**

| | | | |
|---|---|---|---|
| Model Development: | 3 people × 1 yr × $125K/yr | $0.38M | |
| Analysis Support: | 7 people × 1 yr × $125K/yr = | $0.88M | |
| Field Tests: | Range time and people = | +$0.05M | |
| Total Investment: | | $1.76M | |
| Direct Savings: | | $100.00M | |
| ROI: | | $100M/$1.76M = | 57 |

**Standard Missile (SM-2 BLK IIIA) DT&E/OT&E Flight Tests.** The Navy was directed to reduce costs by $47M on the planned flight tests. This required the elimination of 13 missile flight tests out of the planned 30 tests. As a result, the Navy was required to upgrade the existing COVART lethality model and the end-game effectiveness model called WHDEVAL to evaluate the performance of the SM-2 at regions of the performance envelope which could not be tested. The missile system was subsequently accepted based on the reduced number of flight tests and an increased amount of simulation and analysis using the above lethality and vulnerability models. Table BIB-16 depicts the ROI.

**Table BIB-16. Standard Missile (SM-2 BLK IIIA) ROI**

| | | | |
|---|---|---|---|
| Model Development: | | | |
| COVART: | 2 people × 2 yr × $125K/yr = | $0.50M | |
| WHDEVAL: | 3 people × 2 yr × $125K/yr = | $0.75M | |
| Analysis Support: | 3 people × 2 yr × $125K/yr = | $0.75M | |
| Lethality Tests: | 2 people × 1 yr × $125K/yr = | +$0.25M | |
| Total Investment: | | $2.25M | |
| Direct Savings: | | $47.00M | |
| ROI: | | $47M/$2.25M = | 21 |

**Phalanx Close in Weapon System (CIWS) Block 0, DSARC III Decision.** After spending more than $125M on development of the Phalanx Naval gun system, the U.S. Congress was ready to cancel the program based on the first test results in 1975. Since a new gun system design would cost at least $125M at that time, Congress was persuaded to delay program cancellation until the necessary analytical models were developed to evaluate the Phalanx performance under all conditions without extensive hardware testing. Within three years, three models were developed and validated based on extensive laboratory lethality tests. The resulting analyses were of sufficient quality to convince Congress to reinstate the original Phalanx program, based primarily on the results of analytical modeling and simulation at a minimum savings of $125M. Table BIB-17 depicts the ROI.

**Table BIB-17. Phalanx CIWS Block 0 ROI**

| | | | |
|---|---|---|---|
| Model Development: | | | |
| Multiple Plate Pen Model: | 3 people × 2 yr × $125K/yr = | $0.75M | |
| Probability of Hit Model: | 2 people × 2 yr × $125K/yr = | $0.50M | |
| Gun Effectiveness Model: | 3 people × 2 yr × $125K/yr = | $0.75M | |
| Analysis Support: | 3 people × 3 yr × $125K/yr = | $1.12M | |
| Lethality Tests: | people and test assets = | +$5.00M | |
| Total Investment: | | $8.12M | |
| Direct Savings: | | $125.00M | |
| ROI: | | $125M/$8.12M = | 15 |

**Phalanx Close in Weapon System (CIWS) Upgrade Tradeoff Study.** Within 10 years after the initial operational capability (IOC) of the Phalanx, the advent of new threats required either development of a new CIWS or improvements in the original Phalanx capability. By using upgraded version of the existing lethality models developed for the original Phalanx CIWS, an in-depth analysis of the various options proved analytically that upgrades to the original Phalanx design would provide the performance to defeat the improved threat without extensive field testing. The consequences of this analysis were to eliminate more than $200M in design and production costs of a new system. Table BIB-18 depicts the ROI.

**Table BIB-18. Phalanx CIWS Upgrade Tradeoff Study ROI**

| | | | |
|---|---|---|---|
| Model Development: | | | |
| Multiple Plate Pen Model: | 3 people × 1 yr × $125K/yr = | $0.38M | |
| Probability of Hit Model: | 2 people × 1 yr × $125K/yr = | $0.25M | |
| Gun Effectiveness Model: | 2 people × 1 yr × $125K/yr = | $0.25M | |
| Analysis Support: | 4 people × 2 yr × $125K/yr = | $0.75M | |
| Additional Lethality Tests: | people and test assets = | +$5.00M | |
| Total Investment: | | $6.63M | |
| Direct Savings: | | $200.00M | |
| ROI: | | $200M/$6.63M = | 30 |

**AIM-7P Sea Sparrow Ship Launches.** The Navy developed a version of the AIM-7 for ship launch against specific threats. Initially, 10 launches were conducted successfully out of a planned 50 launches. The cost of each launch was $150K for the missile and $250K for the actual test; or a total of $400K each. By using SCAN, the Navy's end-game effectiveness model, to predict the lethality of the missile for the 40 remaining flight tests the Navy was able to eliminate $16M in flight test costs. In addition, the use of lethality analysis instead of actual flight tests reduced the total time required to put the AIM-7P into production. Table BIB-19 depicts the ROI.

**Table BIB-19. AIM-7P Sea Sparrow ROI**

| | | | |
|---|---|---|---|
| Model Development:<br>Analysis Support:<br>Laboratory Tests: | 2 people × 6 mo × $125K/yr =<br>3 people × 1 yr × $125K/yr =<br>people and hardware = | $0.12M<br>$0.38M<br>+$0.20M | |
| Total Investment:<br>Direct Savings:<br>ROI: | <br>40 tests at $400K each =<br> | $0.70M<br>$16.00M<br>$16M/$0.7M = | <br><br>23 |

**Phoenix Missile 6 vs. 6 Tests.** The Navy conducted dozens of live firings of the Phoenix air-air missile during development and operational testing of the system. With a production missile cost of $2M each, a single live firing against one drone costs in excess of $2.5M. Multiple firings of six Phoenix missiles against six target drones simultaneously cost in excess of $14M. In recent years SCAN, the Navy's end-game effectiveness model, has been used to negate the need for additional 6 vs. 6 live firing tests every time a new threat is encountered or when the Phoenix missile has a new upgrade. Over many years, lethality modeling has been successfully used five times for 6 vs. 6 analysis, with a savings in test costs on the order of $70M. Table BIB-20 depicts the ROI.

**Table BIB-20. Phoenix Missile 6 vs. 6 Tests ROI**

| | | | |
|---|---|---|---|
| Model Development:<br>Analysis Support:<br>Laboratory Tests: | 2 people × 2 yr × $125K/yr<br>5 tests 3 people × 4 mo x $125K/yr = | $0.50M<br>$0.63M<br>+$1.10M | |
| Total Investment:<br>Direct Savings:<br>ROI: | | $2.23M<br>$70.00M<br>$70M/$2.23M = | <br><br>31 |

**Electronic Countermeasures (ECM) Against Navy AMRAAM.** The Navy has conducted hundreds of flight tests of ECM against AMRAAM at $700,000 per sortie with approximately 10 intercepts per sortie. This costly procedure has been largely replaced by using a modified version of SCAN, the Navy's end-game effectiveness model, to evaluate the performance of AMRAAM when subjected to numerous types of ECM waveforms. Although some flight tests are still conducted, thousands of engagement simulations using the SCAN model are now used routinely to replace flight test. The savings are in the millions of dollars per year and are expected to continue yearly as new ECM techniques are evaluated. Table BIB-21 depicts the ROI.

**Table BIB-21. ECM Against Navy AMRAAM ROI**

| | | | |
|---|---|---|---|
| Model Upgrade:<br>Analysis Support:<br>ECM Support from Lab: | 1 person × 1 yr × $125K/yr<br>2 people × 1 yr × $125K/yr = | $0.13M<br>$0.25M<br>+$0.20M | |
| Total Investment:<br>Direct Savings (1 yr):<br>ROI: | 150 missions × $70,000 ea = | $0.58M<br>$10.50M<br>$10.5M/$0.58M = | 18 |

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[Tillson et al. 1992]

J. C. Tillson, M. L. Roberson, and S. A. Horowitz. *Alternative Approaches to Organizing, Training and Assessing Army and Marine Corps Units. Part II: The Reserve Component*. Institute for Defense Analyses, Alexandria, VA, November 1992.

There are two goals for this two-part study. Part I seeks to develop alternative approaches to organizing the Active Component of the U.S. Army and the U.S. Marine Corps to allow both Services to maintain force structure and training readiness despite anticipated reductions in resources and operating tempo. In Part II, the goal is to develop and analyze alternative ways of organizing and training Reserve combat forces that will allow them to better serve the nation's diverse needs. The study also addresses changes in the world that make this study important, such as the shape of the future battlefields and the implications these battlefields will have on future training and organizing of U.S. forces. Chapter 7, "New Approaches to Using Simulation for Training," and Chapter 8, "New Approaches to Using Simulators for Training" are the most interesting to the modeling and simulation community. These chapters describe a new approach to using virtual and constructive simulation for training the Army National Guard (ARNG) and U.S. Marine Corps Reserve (USMCR) combat maneuver units. It adapts current simulations to training for the Active Component to geographically removed Reserve and National Guard units by applying new technologies available for distance learning. This linkage for distance learning allows training as a cohesive unit. Previously, geographically separated units had virtually no options available to them if they desired to leverage the Active Component simulation exercises. Now, ARNG and USMCR units are able to experience the same staff training exercises available to the Active Component.

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[Turnage and Bliss 1990]

J. J. Turnage and J. P. Bliss. *An Analysis of Skill Transfer for Tank Gunnery Performance Using TOPGUN, VIGS, and ICOFT Trainers.* ARI Technical Report 916. USA Research Institute for the Behavioral and Social Sciences, Alexandria, VA, 1990.

Researchers studied the transfer of training from two part-task trainers to a full-fidelity gunnery simulator. Significant performance transfer was found from both part-task trainers and full-task simulators. Research demonstrated how different gunnery trainers may be used separately or together to improve gunnery skills and to provide support for using less expensive part-task devices for training basic gunnery skills.

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[Watson and Cooper 1988]

B. A. Watson and R. B. Cooper. *Relating Tank Gunnery Performance to Operational Effectiveness (Study Summary).* USA TRADOC Systems Analysis Activity, White Sands Missile Range, NM, 1988.

*No abstract available.*

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[Wilhoite 1993]

B. K. Wilhoite. "Bytes vs. Bullets: Crew-Served Weapons Simulation Based Training." *Proceedings of the 15th Interservice/Industry Training Systems and Education Conference*, Orlando, FL, December 1993, 475-480.

Wilhoite describes the ongoing evaluation of the Indoor Simulated Marksmanship Trainer (ISMT), an advanced small-arms trainer capable of providing simulation training for individuals and teams for every weapon in a U.S. Marine Corps infantry battalion. Students who were able to use Precision Gunnery Training System (PGTS) in addition to traditional instruction generally performed better than those receiving traditional training alone. Significant cost savings are possible as simulation is used in lieu of live fire during training.

[Winsch et al.1994]

B. J. Winsch, N. K. Atwood, A. R. Sawyer, K. A. Quinkert, C. K. Heiden, P. G. Smith, and B. Schwartz. *Innovative Training Concepts for Use in Distributed Interactive Simulation Environments.* ARI Research Product 94-16. USA Research Institute for the Behavioral and Social Sciences, Alexandria, VA, 1994.

This report describes innovative approaches for conducting training using emerging simulation technology. It is intended as a forward-looking reference for training developers and trainers interested in conducting specific types of training exercises using Distributed Interactive Simulations (DIS). The report presents five innovative training concepts that can be structured within a DIS environment for delivery of five types of training exercises, including a Battle Staff Planning Exercise, a Leader's Reconnaissance Exercise, a Mission Rehearsal Exercise (Electronic Sandtable), a Mission Execution Exercise (Electronic Sandbox), and an Information Management Exercise. The report concludes with a description of the implementation of one of these five concepts, an Information Management Exercise (IMEX).

# ABBREVIATIONS AND ACRONYMS

| | |
|---|---|
| AAAV | Advanced Amphibious Assault Vehicle |
| ACR | Aerial Cable Range; Armored Cavalry Regiment |
| ADS | Advanced Distribution Simulation |
| AIAG | Automotive Industry Action Group |
| AEDC | Arnold Engineering Development Center (U.S. Air Force) |
| AFB | Air Force Base |
| AFSAA | Air Force Studies and Analyses Agency |
| AGS | Armored Gun System |
| ALSP | Aggregate Level Simulation Protocol |
| AMRAAM | Advanced Medium Range Air to Air Missile |
| AP | Agile Provider |
| ARI | Army Research Institute for the Behavioral and Social Sciences |
| ARNG | Army National Guard |
| ARTEP | Army Training and Evaluation Program |
| ATC | Aberdeen (MD) Test Center |
| ATCSS | Army Tactical Command and Control System |
| BBS | Brigade/Battalion Battle Simulation |
| BCST | Battle Command Staff Training |
| BFTT | Battle Force Tactical Training |
| BKEP | Boosted Kinetic Energy Penetrator |
| BRAC | Base Realignment and Closure |
| C3 | Command, Control, and Communications |
| C3ISIM | Command, Control, Communications, and Intelligence Simulation |
| C4I | Command, Control, Communications, Computers, and Intelligence |
| CAD | Computer-Assisted Design |
| CAE | Computer-Assisted Engineering |
| CAM | Computer-Assisted Manufacturing |
| CAS | Close Air Support |
| CASE | Combined Arms Synthetic Experiment |
| CAT | Canadian Army Trophy |
| CAX | Computer-Aided Exercise |
| CCTT | Close Combat Tactical Trainer |
| CD-ROM | Compact Disk - Read Only Memory |

| | |
|---|---|
| CFE | Conventional Forces in Europe |
| CGF | Computer Generated Forces |
| CGSC | Command and General Staff College (U.S. Army) |
| CINCCENT | Central Command |
| CJCS | Chair, Joint Chiefs of Staff |
| CMTC | Combat Maneuver Training Center |
| COEA | Cost and Operational Effectiveness Analysis |
| COFT | Conduct of Fire Trainer |
| CREWS | Covert Remote Electronic Warfare Simulator |
| CSTS | Combat Simulation Test System |
| CTEA | Cost and Training Effectiveness Analysis |
| CTC | Combat Training Center |
| DARPA | Defense Advanced Research Projects Agency |
| DFO-MULE | Deployable Forward Observer - Modular Universal Laser Equipment |
| DIRSP | Dynamic Infrared Scene Projector |
| DIS | Distributed Interactive Simulation |
| DISA | Defense Information Systems Agency |
| DMDC | Defense Manpower Data Center |
| DMSO | Defense Modeling and Simulation Office |
| DoD | Department of Defense |
| DSARC | Defense Systems Acquisition Review Council |
| DSB | Defense Science Board |
| DSI | Defense Simulation Internet |
| DT | Developmental Test |
| EADSIM | Extended Air Defense Simulation |
| ECM | Electronic Countermeasures |
| EIGHT | Environmental Issues Guide for Heuristic Testing |
| EMD | Engineering and Manufacturing Development |
| EPG | Electronic Proving Ground |
| EPLRS | Enhanced Position Location Reporting System |
| FAADS/ADATS | Forward Area Air Defense System/Air Defense, Anti-Tank System |
| FDT&E | Force Development Test and Experimentation |
| FFRDC | Federally Funded Research and Development Center |
| FIS | Firing Impulse Simulator |
| FLEETEX | Fleet Training Exercise |
| FOG | Fiber Optics Guidance |

| | |
|---|---|
| G | Gravity (force) |
| GAO | General Accounting Office |
| GM | General Motors |
| GUARDFIST | Guard Unit Armory Device Full-Crew Interactive Simulation Trainer |
| HAWK | Homing-All-The-Way Killer (missile) |
| CIWS | Close in Weapon System |
| HMMWV | High-Mobility Multi-Purpose Wheeled Vehicle (Hummer) |
| HWIL | Hardware in the Loop |
| ICOFT | Institutional Conduct of Fire Trainer |
| IDA | Institute for Defense Analyses |
| IMEX | Information Management Exercise |
| IOT&E | Initial Operational Test and Evaluation |
| IPPD | Integrated Product and Process Development |
| IRIAM | Integrated Radar and Infrared Analysis Modeling |
| ISAS | Intelligence Shelter Attack Submunition |
| ISMT | Indoor Simulated Marksmanship Trainer |
| IST | Institute for Simulation Technology |
| ITE | Integrated Test and Evaluation |
| ITS | Interface Test Set |
| JCS | Joint Chiefs of Staff |
| JPSD | Joint Precision Strike Demonstration |
| JSTARS TE | Joint Surveillance Target Acquisition Radar Terminal Emulation |
| JTC | Joint Training Confederation |
| JTIDS | Joint Tactical Information Distribution System |
| JWCA-OR | Joint Warfare Concept Analysis - Operations Research |
| JWID | Joint Warrior Interoperability Demonstration |
| K | Thousand |
| KEP | Kinetic Energy Penetrator |
| LAMPS | Light Airborne Multipurpose System |
| LAV | Light Armored Vehicle |
| LCS | Liquid Crystal Display |
| LDWSS | Laser Designator Weapon System Simulation |
| LMTTU | Light Airborne Multipurpose System (LAMPS) I/III Mobile Team Trainer Unit |
| L/V | Lethality and Vulnerability |
| M | Million |

| | |
|---|---|
| M&S | Modeling and Simulation |
| MACS | Multipurpose Arcade Combat Simulator |
| MATT | Multi-Mission Advanced Tactical Terminal |
| MAWS | Missile Approach Warning System |
| MBST | Marine Battle Skill Training |
| MCAGCC | Marine Corps Air Ground Combat Center |
| MCMSMO | Marine Corps Modeling and Simulation Management Office |
| MDT2 | Multi-Service Distributed Training Testbed |
| MILES | Multiple Integrated Laser Engagement System |
| ModSAF | Modular Semi-Automated Forces |
| MOE | Measure of Effectiveness |
| MOP | Measure of Performance |
| MORS | Military Operations Research Society |
| MOS | Military Occupational Specialty qualifications |
| MRTFB | Major Range and Test Facility Base |
| MSBTF | Modeling and Simulation Benefits Task Force |
| MSE | Mobile Subscriber Equipment |
| MTP | Mission Training Plan |
| MTS | Moving Target Simulator |
| MULTIRAD | Multiship Research and Development program |
| NASA | National Aeronautics and Space Administration |
| NATO | North Atlantic Treaty Organization |
| NAWCWD | Naval Air Warfare Center, Weapons Division |
| NLOS | Non Line of Sight |
| NSC | National Simulation Center |
| NTC | National Training Center |
| O&M | Operations and Maintenance |
| OEM | Original Equipment Manufacturer |
| OPTEMPO | Operating Tempo |
| OR | Operations Research |
| OSD | Office of the Secretary of Defense |
| OT | Operational Test |
| OT&E | Operational Test and Evaluation |
| PAC-3 | Patriot Advanced Capability - 3 |
| PC | Personal Computer |
| P&L | Production and Logistics |

| | |
|---|---|
| PGTS | Precision Gunnery Training System |
| R&D | Research and Development |
| RAVIR | Radar Video Recorder |
| RC | Reserve Component |
| RDEC | Research, Development and Engineering Center (U.S. Army) |
| RDT&E | Research, Development, Test and Evaluation |
| REFORGER | Return of Forces to Germany |
| RFI | Request for Information |
| RFTOP | Rooftop Transmitter Device |
| ROI | Return on Investment |
| RTTC | Redstone (AL) Technical Test Center |
| RSAS | RAND Strategy Assessment System |
| RSL | Received Signal Level |
| SAC | Strategic Air Command |
| SADARM | Sense and Destroy Armor Simulation |
| SAM3 | Software Acquisition Management Maturity Model |
| SARDS | Situational and Reality Display System |
| SAW | Squad Automatic Weapon |
| SDF | Sensor Data Fusion |
| SETS | Squad Engagement Training System |
| SIF | Standard Interchange Format |
| SIM2 | Simulator/Simulation-Based Training Program Analysis |
| SIMNET | Simulator Networking |
| SM | Standard Missile |
| SMART | Simulation and Modeling Anchored by Real Testing |
| SOP | Standard Operating Procedure |
| STAF | Simulation/Test Acceptance Facility |
| STOW-E | Synthetic Theater of War - Europe |
| STRATA | Simulator Training Research Advanced Testbed for Aviation |
| STRICOM | Simulation, Training, and Instrumentation Command |
| STX | Situational Training Exercise |
| SUMS | Simulation Utility Management System |
| TAC-DM | Tactical Decision Making |
| TACDEW | Tactical Advanced Combat Direction and Electronic Warfare |
| TACSIM | Tactical Simulation |
| TACWAR | Tactical Warfare |

| | |
|---|---|
| TAMIP | Target Acquisition Model Improvement Program |
| TECOM | Test and Evaluation Command (U.S. Army) |
| TES | Tactical Engagement Simulation |
| TIS | Test Item Stimulators |
| TILV | Target Interaction, Lethality and Vulnerability |
| TIS | Test Item Simulator |
| TOW | Tube Launched, Optically Tracked, Wire Guided |
| TQM | Total Quality Management |
| TRUE | Training Requirements Utility Evaluation |
| TTP | Tactics, Techniques, and Procedures |
| TWGSS | Tank Weapons Gunnery Simulation System |
| UCOFT | Unit Conduct of Fire Trainer |
| UE | Unified Endeavor |
| USA | United States Army |
| USACOM | United States Atlantic Command |
| USAF | United States Air Force |
| USAMICOM | United States Army Missile Command |
| USMC | United States Marine Corps |
| USMCR | United States Marine Corps Reserve |
| USMTF | United States Message Text Format |
| V/V | Verification and Validation |
| VR | Virtual Reality |
| VTF | Vibration Test Facility |
| VTR | Virtual Test Range |
| VV&A | Verification, Validation, and Accreditation |
| WAAM | Wide-Area Anti-Armor Munition |
| WSMR | White Sands Missile Range |
| WSSF | Weapons Software Support Facility |
| YPG | Yuma (AZ) Proving Grounds |

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13. ABSTRACT (Maximum 200 words)
DoD has invested heavily in modeling and simulation (M&S) capabilities in recent years. Developers are confident about the payoff of these investments, yet little has been done to assess systematically the cost effectiveness or return on investment. This study documents the Modeling and Simulation Benefits Task Force's preliminary efforts to quantify the effects of M&S on the functional areas of training, acquisition, and analysis. Responses to two Requests for Information (RFIs) and other DoD organizations' assessments provide a baseline of information on which a long-term Impact Assessment is being conducted. Over one hundred reports, ranging from the anecdotal to the formal, were collected, categorized by functional area, and summarized. Each report is abstracted in an annotated bibliography. In addition, two appendices are provided. The first identifies the types of measures of effectiveness (MOEs) that are being used in the field and offers candidate MOEs for future assessments. The second appendix argues the relative merits of some common methods of calculating cost effectiveness and offers suggestions for improving the quality of assessment in the future.

14. SUBJECT TERMS
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